National Aeronautics and Space Administration

UAS Integration in the NAS Project Part Task 5 DAA Display Evaluation III Primary Results

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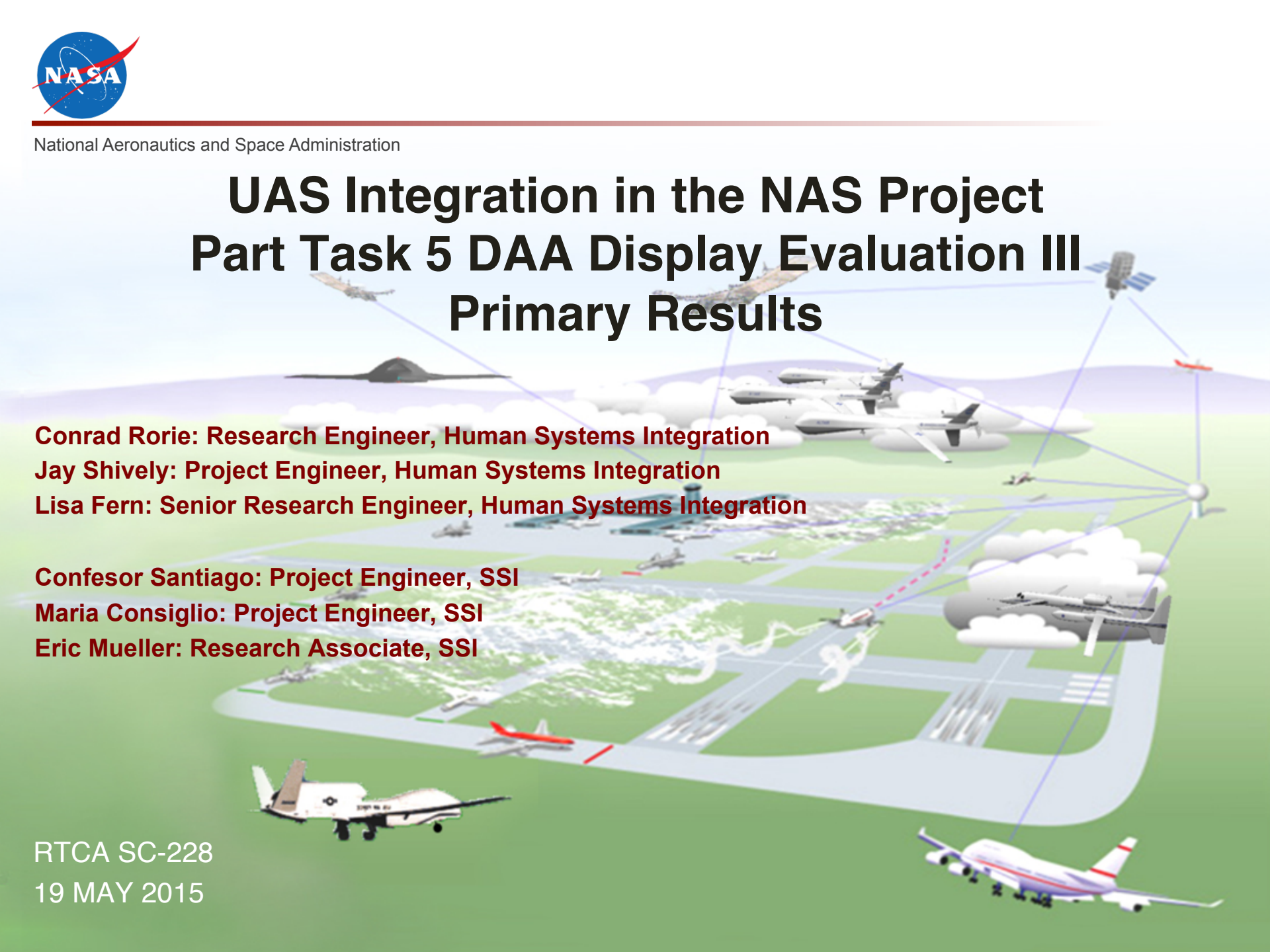

RTCA SC-228
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Outline

- Background
- Experimental Design and Procedure
- Displays and Alerting Structure
- Results
  - Losses of Well Clear
  - Measured Response
  - Subjective Feedback
- Summary

PT5 Background

- Motivation
  - Build upon previous human-in-the-loop simulations results and lessons learned to identify minimum DAA display and guidance requirements for draft SC228 MOPS
    - PT4
      - A suite of integrated guidance tools led to faster pilot responses, fewer losses of well clear and less severe losses of well clear when they did occur
    - iHITL
      - Integrated guidance tools led to less severe losses of well clear and faster pilot responses than seen in PT4
    - AFRL Maneuver Study
      - Guidance (in the form of 'banding') led to faster pilots responses and fewer collision avoidance alerts

PT5 Background

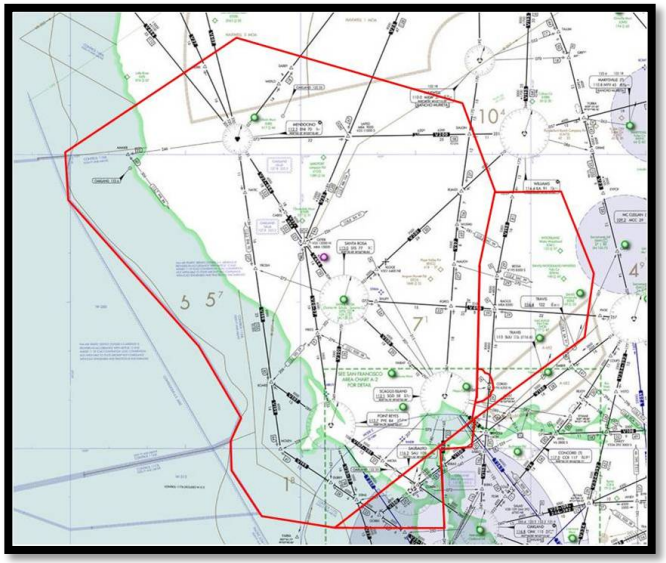
- Modifications from previous sims:
  - Guidance tools were no longer tightly coupled to the ground control station's auto pilot interface
  - Removed advanced features present in iHITL (e.g., well clear ring & dead reckoning lines)
  - Modeled sensor uncertainty for the first time
    - Critical to test displays and algorithms with 'imperfect' data prior to flight tests
  - Implemented alerting structure as part of the draft MOPS
  - Increased workload on the pilot
    - More secondary tasks and interaction with their route

Experimental Design

- Mixed Factorial Design
  - *Display Configuration* (Within-Subjects Independent Variable):
    - **Configuration 1**: Minimum Information Set (No Guidance)
    - **Configuration 2**: Stratway+ No Fly Bands
    - **Configuration 3**: JADEM Omni Bands
    - **Configuration 4**: JADEM Vector Planning Tools
  - *Sensor Performance* (Between-Subjects Independent Variable)
    - **Level 1**: Perfect Surveillance Data
    - **Level 2**: Imperfect Surveillance Data
- Embedded Variable
  - *Intruder Equipage* (manipulated within each scenario)
    - Transponder-equipped (detected via UAS's ADS-B)
    - No Transponder (detected via UAS's on-board RADAR)

Experimental Design

- Participants
  - 16 active UAS pilots
    - Avg. 37 years old (all male)
    - Manned Flying Experience
      - Civil airspace: 575 avg. hrs
      - Military: 1760 avg. hrs
    - Unmanned Flying Experience
      - Civil airspace: 30 avg. hrs
      - Military: 1100 avg. hrs



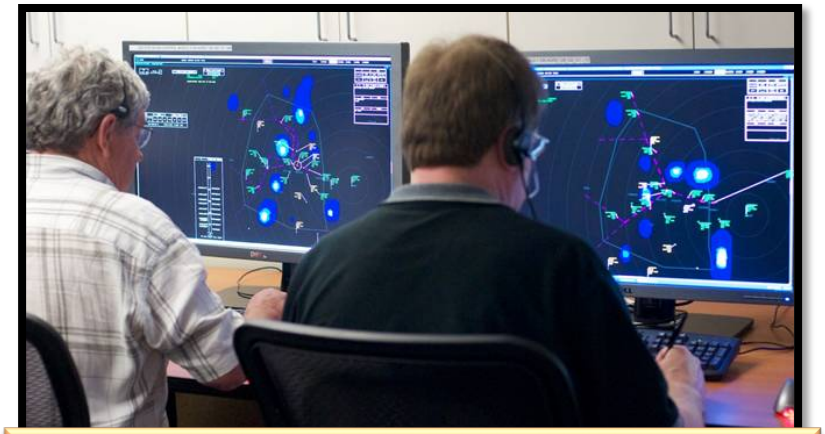
- Task
  - Fly simulated MQ-9 through Class E airspace (Oakland Center – ZOA 40/41)
    - Navigate along pre-filed routes (used AFRL's Vigilant Spirit Control Station)
    - Maintain well clear from pre-scripted conflicts
    - Coordinate with ATC
    - Attend to secondary tasks (e.g., chat messages, system alerts)

Experimental Design

- Pre-planned conflicts with ownship
  - 6 scripted encounters predicted to lose well clear
    - 3 with cooperative traffic (detected at max range of 15nm)
    - 3 with non-cooperative traffic (detected at max range of 8nm, with limited FoR)
  - 3 scripted encounters predicted to become preventive self separation alerts
- Dependent measures
  - Losses of well clear
    - Rates, severity and type
  - Pilot measured response
    - Initial & total response times
    - Communication and edit times
  - Subjective Feedback
    - Post-Trial/Simulation questionnaires, debrief

Experimental Design

- Simulation confederates
  - NATCA controller managed UAS and manned traffic within ZOA 40/41
    - Simulated manned traffic based on actual sector activity
  - Pseudo-pilots managed all manned traffic to provide dynamic sector activity
  - ATC SME operated as 'ghost' controller to ensure conflicts were generated



Air Traffic Control Station (MACS)

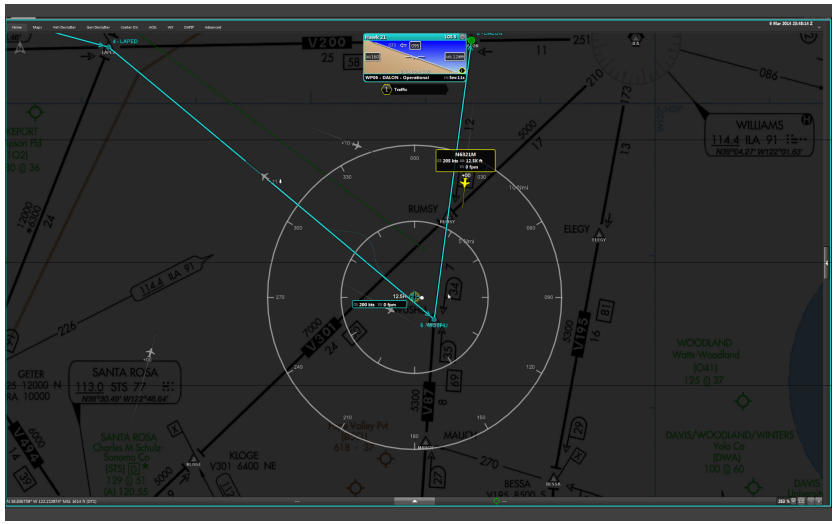
Pseudo Pilot Station

Draft MOPS Alerting Structure

Symbol	Name	Pilot Action	Buffered Well Clear Criteria	Time to Loss of Well Clear	Aural Alert Verbiage
	Self Separation Warning Alert	• ***Immediate action required*** • Notify ATC as soon as practicable after taking action	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	25 sec (TCPA approximate: 60 sec)	"Traffic, Maneuver Now"
	Corrective Self Separation Alert	• On current course, ***corrective action required*** • Coordinate with ATC to determine an appropriate maneuver	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	75 sec (TCPA approximate: 110 sec)	"Traffic, Separate"
	Preventive Self Separation Alert	• On current course, corrective action ***should not be required*** • Monitor for intruder course changes • Talk with ATC if desired	DMOD = 0.75 nmi HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec	75 sec (TCPA approximate: 110 sec)	"Traffic, Monitor"
	Self Separation Proximate Alert	• Monitor target for potential increase in threat level	DMOD = 0.75 nmi HMD = 1.5 nmi ZTHR = 1200 ft modTau = 35s	85 sec (TCPA approximate: 120 sec)	N/A
	None (Target)	• No action expected	Within surveillance field of regard	X	N/A

Display Conditions

D1



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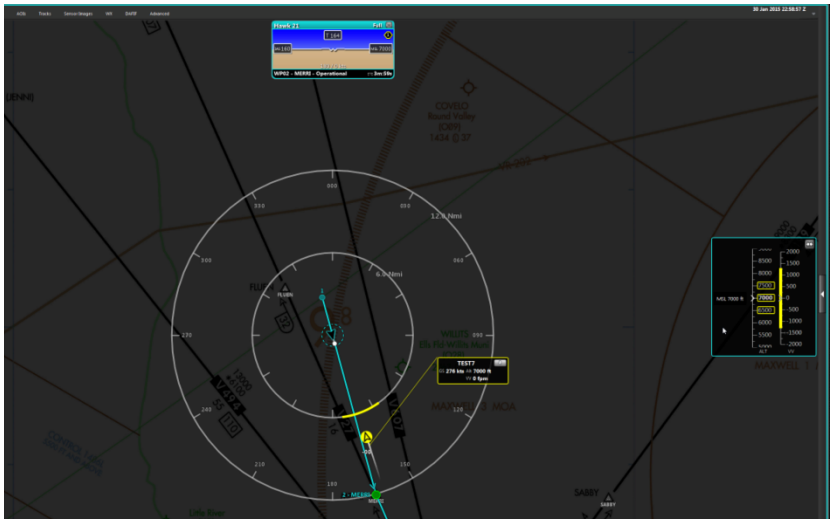

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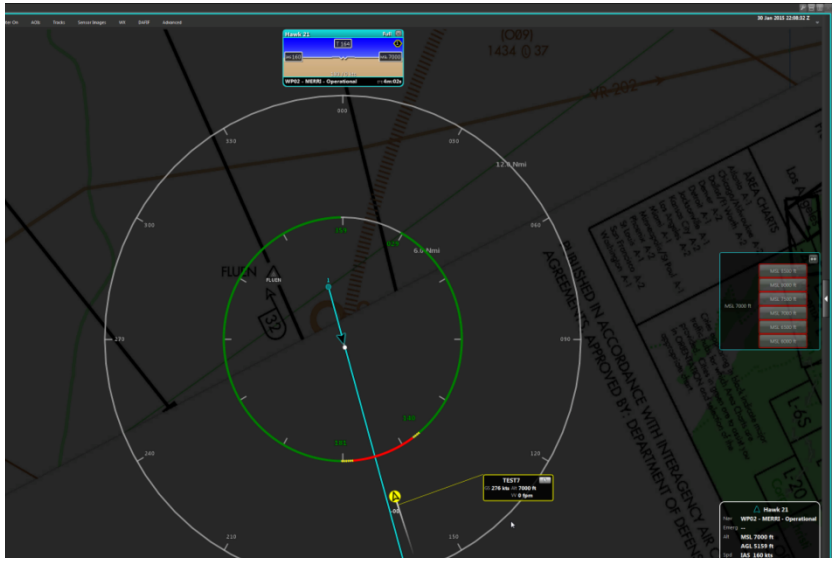
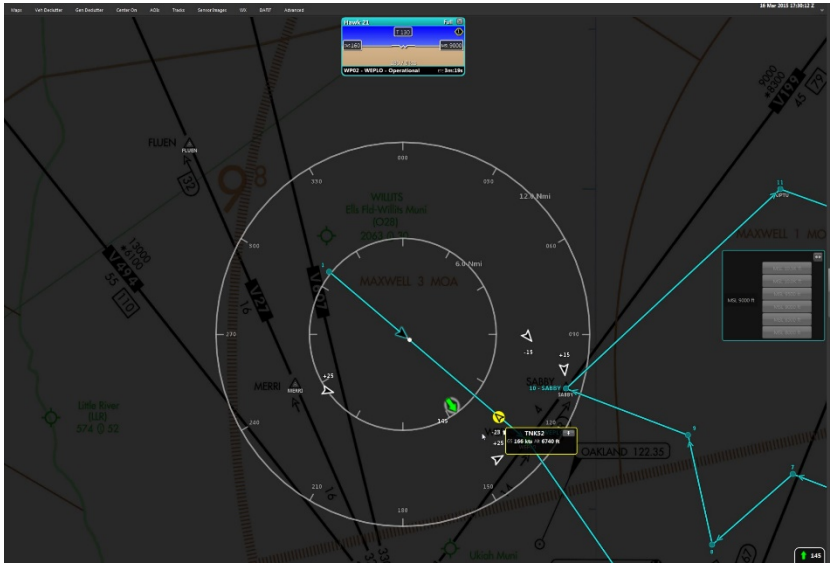
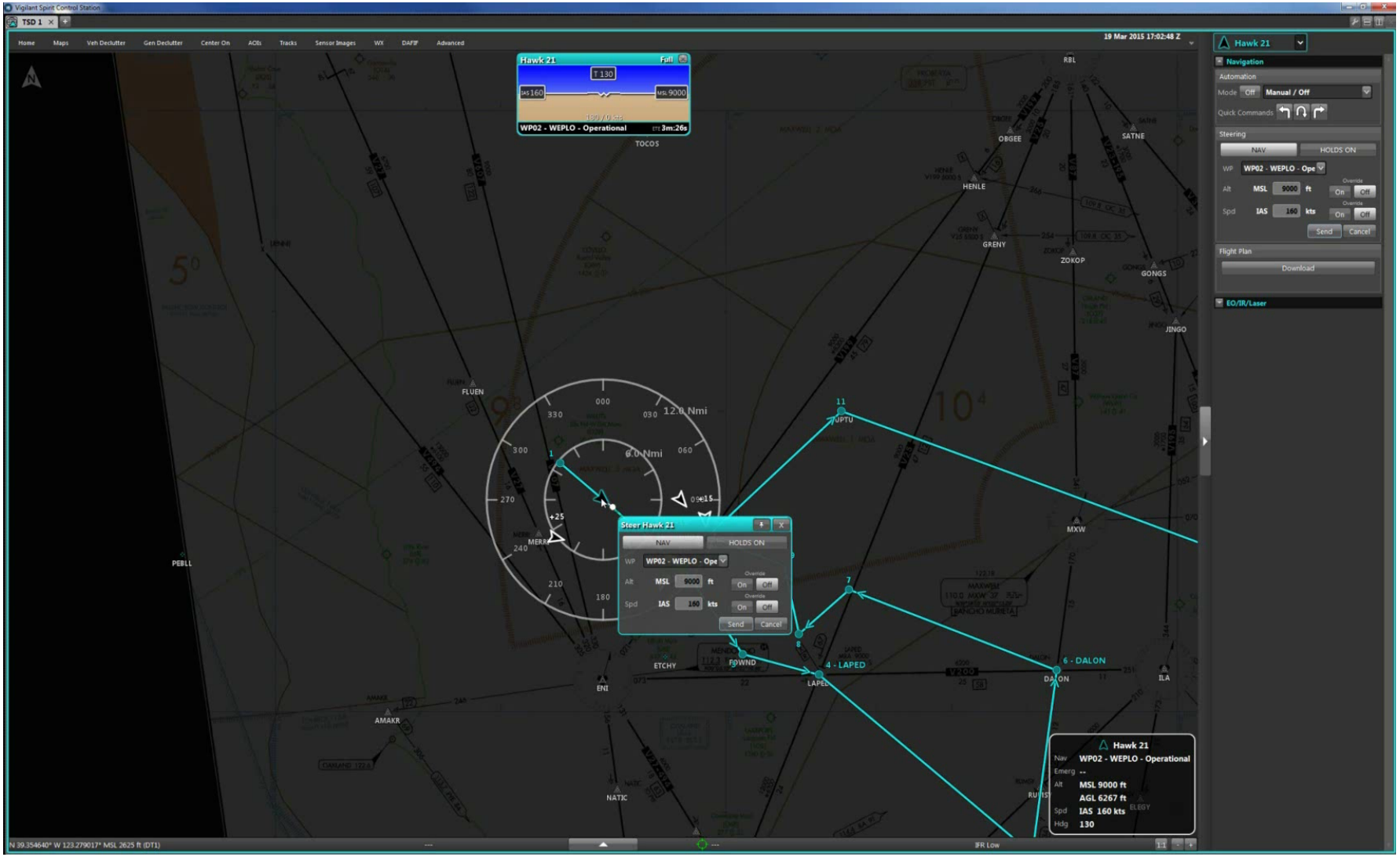


D4



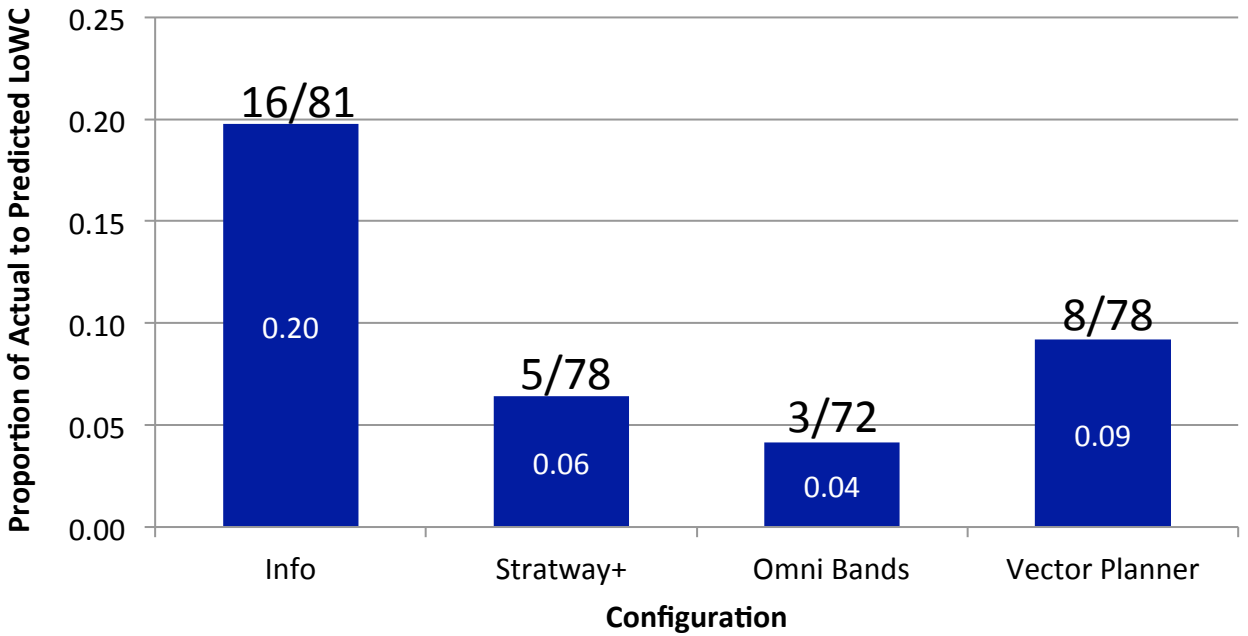
Display Conditions



LOSS OF WELL CLEAR DATA

- LoWC Rate (by Display)
- LoWC Categories
- LoWC Severity (by Display)

Actual vs. Predicted Losses of Well Clear



- Did the pilot's ability to prevent losses of well clear differ by display?
  - Info Only (**19.8%**) was roughly *four times* as likely as Stratway+ (**6.5%**) and Omni Bands (**4.2%**) to result in LoWC, a significant difference ($p<.05$)
    - Info Only was roughly *two times* as likely as Vector Planner (10.3%) to lead to LoWC, which approached significance ($p=.086$)
  - No significant differences seen between the three guidance displays in terms of LoWC

LoWC by Pilot

Statistical Significance	Info Only	Stratway+	OmniBands	Vector Plan.
Info Only	1	**0.016**	**0.002**	0.087
Stratway+	**0.016**	1	0.256	0.560
OmniBands	**0.003**	0.260	1	0.123
Vector Plan.	0.087	0.557	0.123	1

	Number of LoWCs by Pilot Number																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**Total**
Info Only :	1	3	1	1	1	2	0	0	2	0	0	1	1	1	2	0	**16**
Stratway+ :	0	1	1	1	0	0	0	0	0	1	0	0	1	0	0	0	**5**
OmniBands :	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	**3**
Vector Planner:	0	0	0	0	0	1	0	1	0	1	0	2	2	0	1	0	**8**
Total	**1**	**4**	**2**	**2**	**1**	**5**	**0**	**2**	**2**	**2**	**0**	**3**	**4**	**1**	**3**	**0**	**59**

- Pilots 2, 6 & 13 had larger number of LoWC
- Pilots 7, 11, 16 had zero LoWC

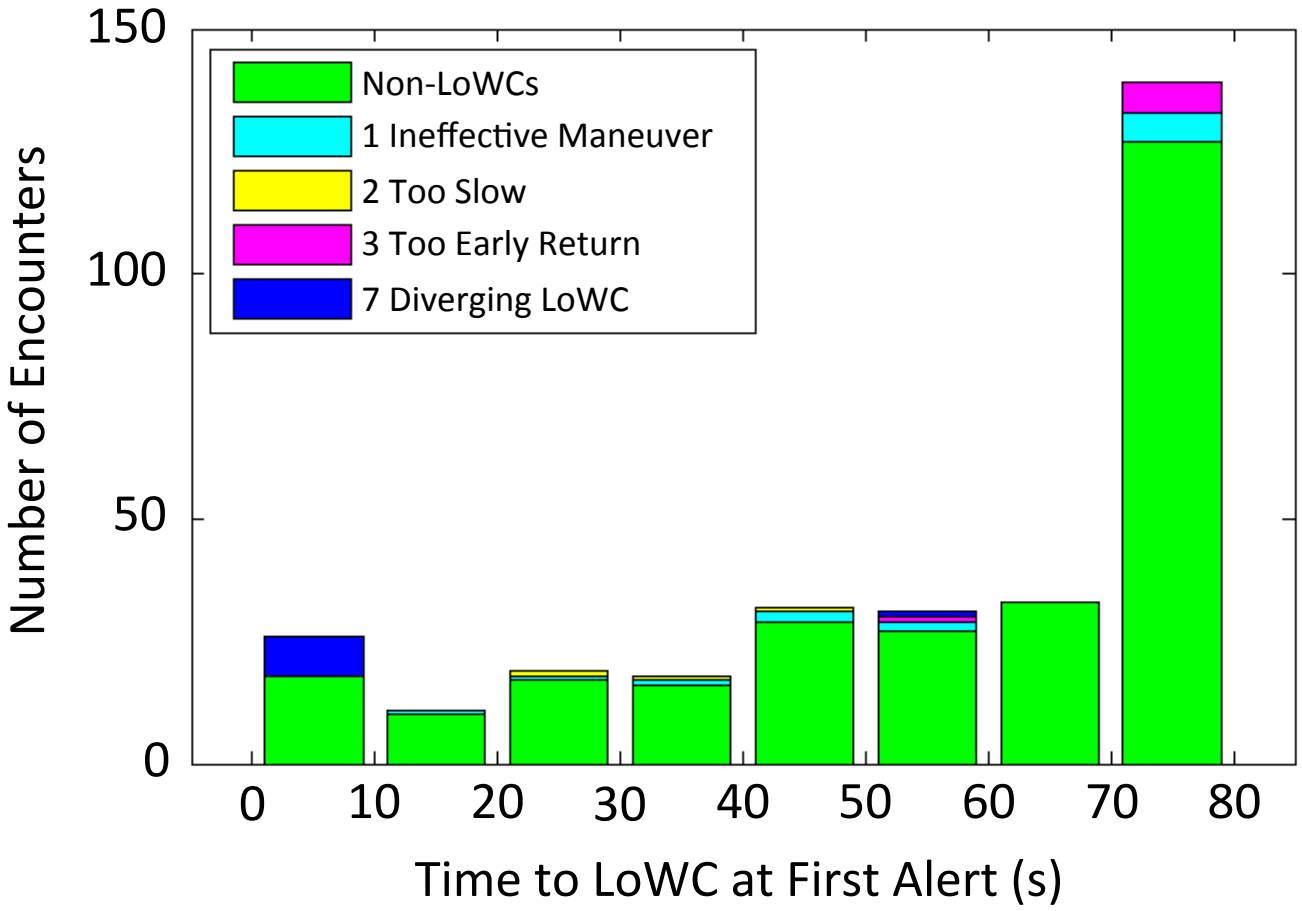
Categories of LoWC

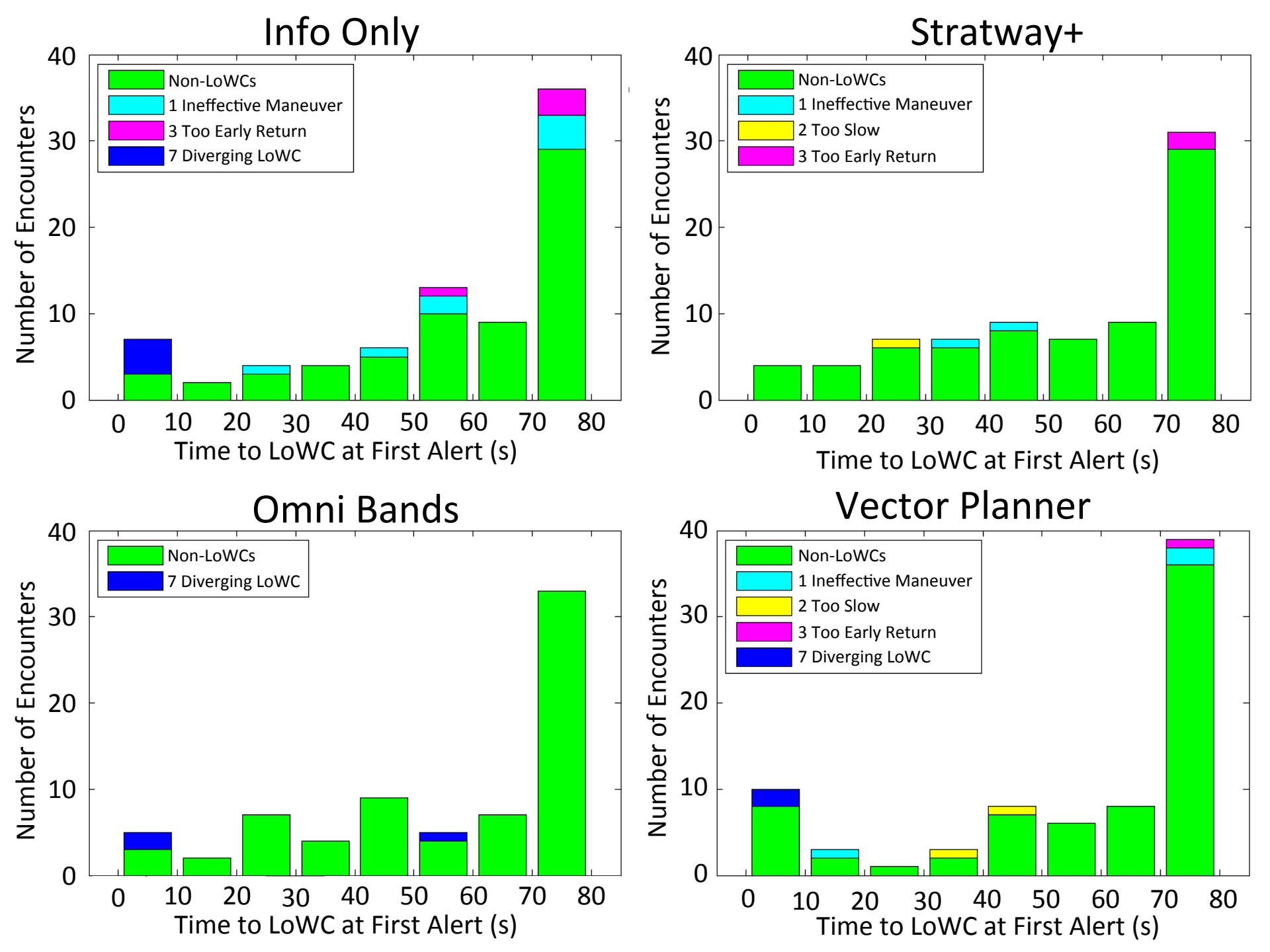
- Assigned each LoWC one of the following categories:

	Code	Type	Description
Pilot Responsibility	1	Ineffective Maneuver	Initial maneuver from traffic was not sufficient to prevent LoWC, even though algorithm was providing accurate information
	2	Too Slow	Pilot did not initiate the maneuver quickly enough (i.e., upload was not sent prior to LoWC or sent very late), even though algorithm was providing accurate information
	3	Too Early Return	Pilot returned to course too early, causing a LoWC with an aircraft they had already successfully avoided
	7	Diverging LoWC	LoWC occurred when ownship and threat were diverging, no visual or aural alert was issued to pilot
Unintentional	Code	Type	Description
	4	Late Intruder Acceleration	State change by the intruder, made with less than 15sec to LoWC, escalated the severity of the encounter
	5	Elevation Error	Intruder (in truth) was level 500ft above or below ownship; altitude error caused LoWC
	8	Vigilant Spirit Malfunction	Bug when Vigilant Spirit was in altitude override mode resulted in the visual/aural alerting failing to issue or issue late

LoWC by Category and Time to LoWC at First Alert

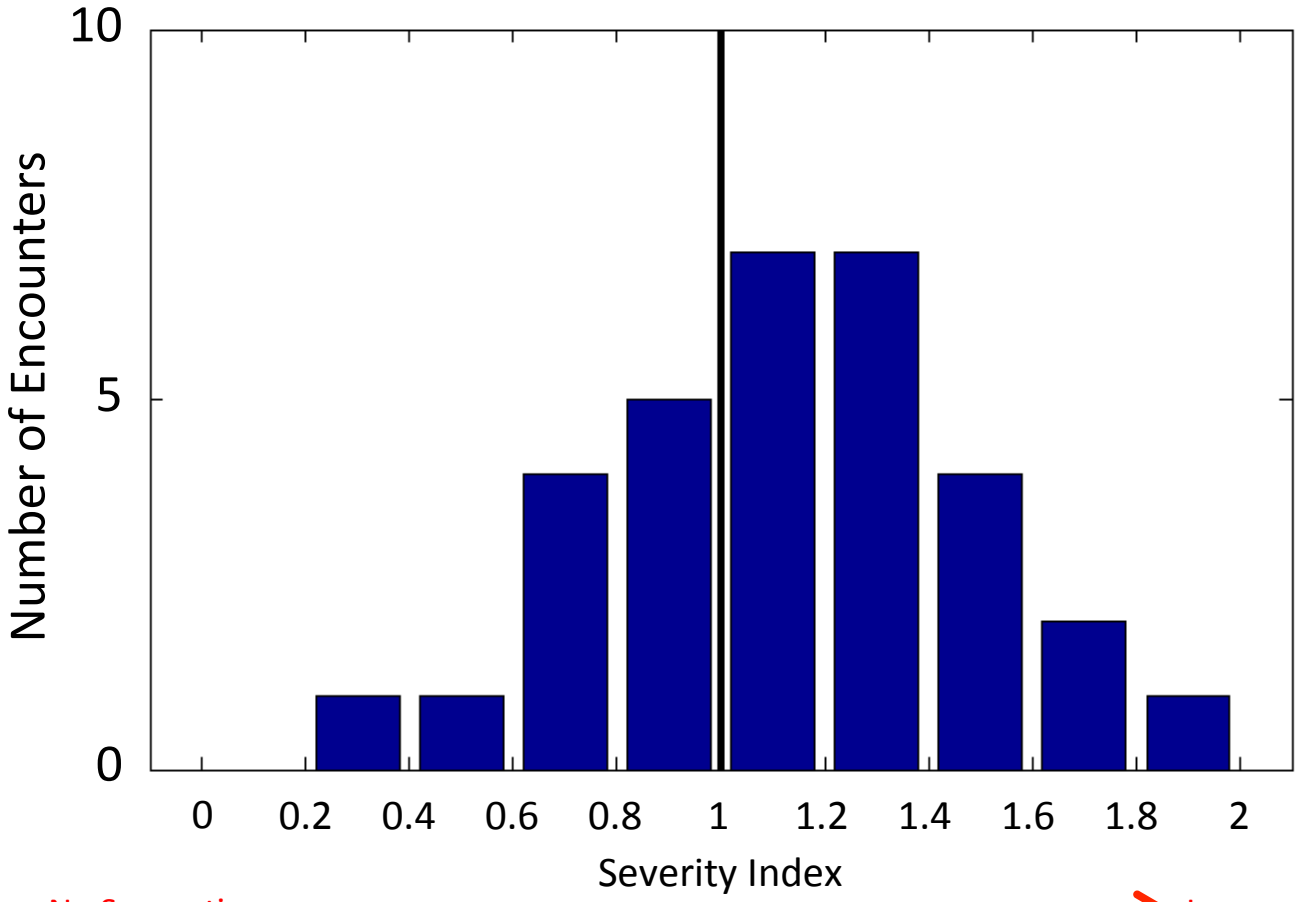
- All Displays:

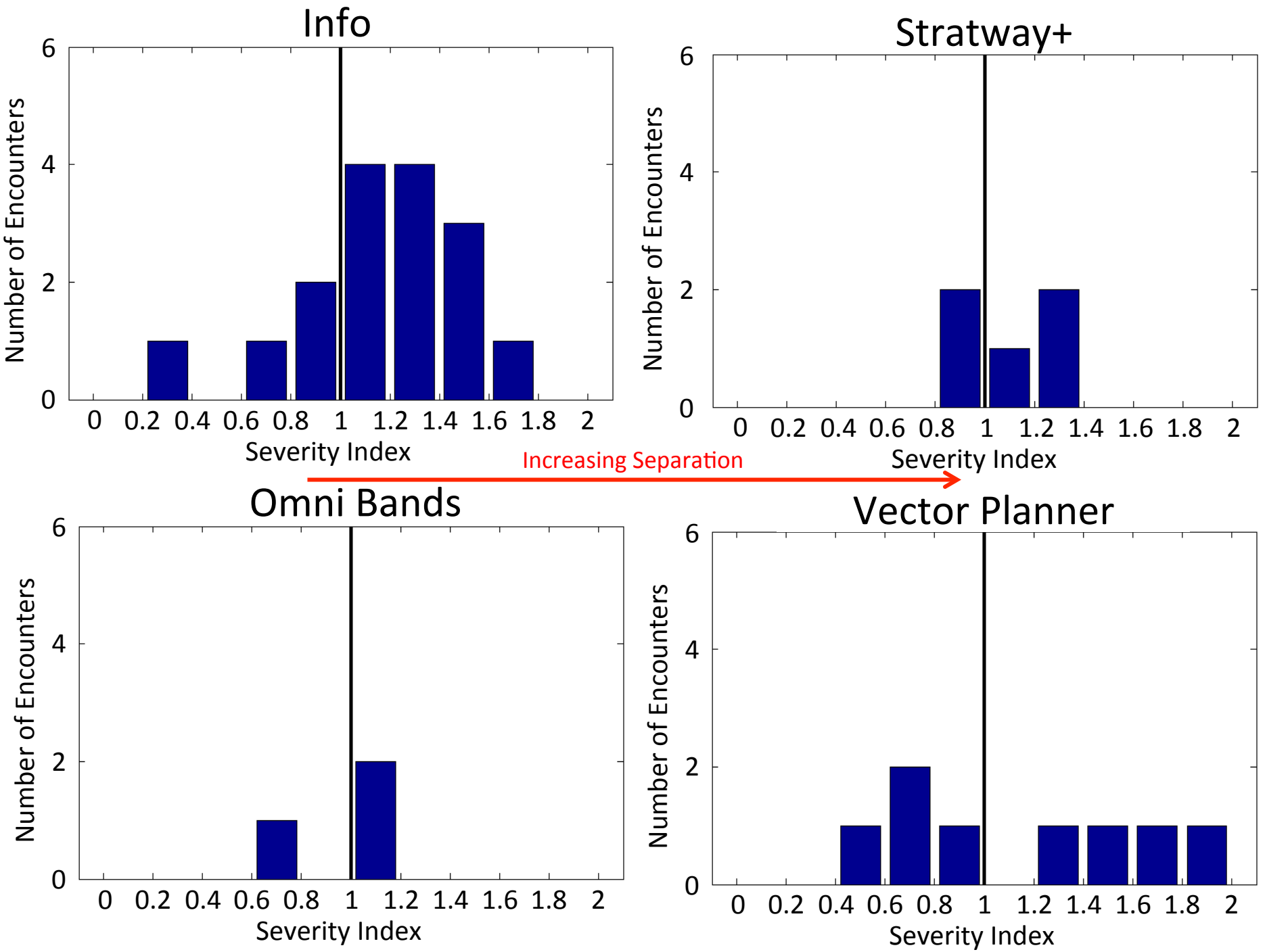



Info Only
Non-LoWCs
1 Ineffective Maneuver
3 Too Early Return
7 Diverging LoWC
Number of Encounters
Time to LoWC at First Alert (s)
Stratway+
Non-LoWCs
1 Ineffective Maneuver
2 Too Slow
3 Too Early Return
Number of Encounters
Time to LoWC at First Alert (s)
Omni Bands
Non-LoWCs
7 Diverging LoWC
Number of Encounters
Time to LoWC at First Alert (s)
Vector Planner
Non-LoWCs
1 Ineffective Maneuver
2 Too Slow
3 Too Early Return
7 Diverging LoWC
Number of Encounters
Time to LoWC at First Alert (s)

LoWC Severity

- All Displays:
  - Actual Separation / Separation Threshold
  - Less than 1 = spatial separation was NOT maintained




Info
Stratway+
Omni Bands
Vector Planner
Number of Encounters
Severity Index
0
2
4
6
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
Increasing Separation

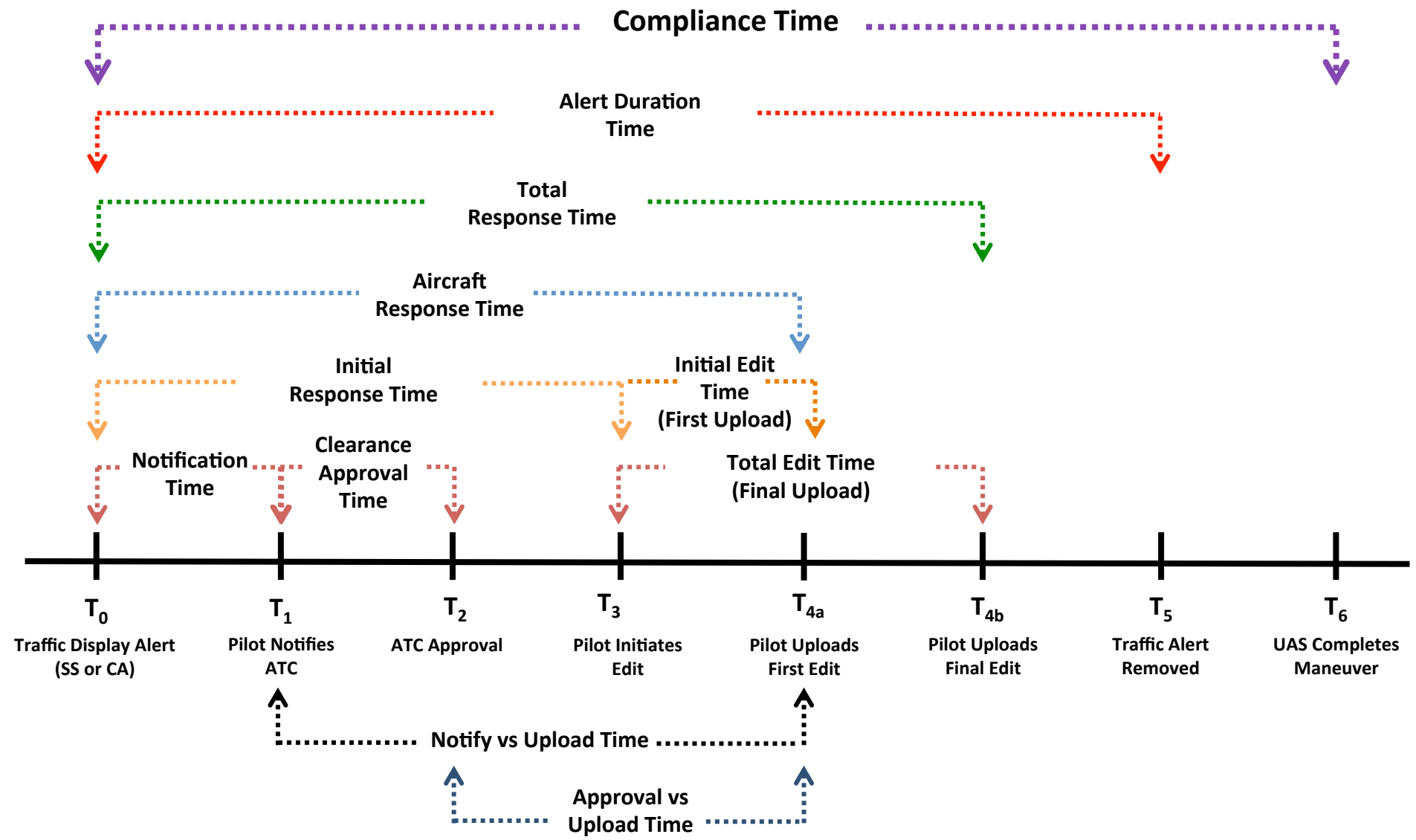
MEASURED RESPONSE DATA

- Total Response Times (by Display)
- Comparison to Previous Sims
- Total Response Times (by Additional Variables)

Encounter Statistics

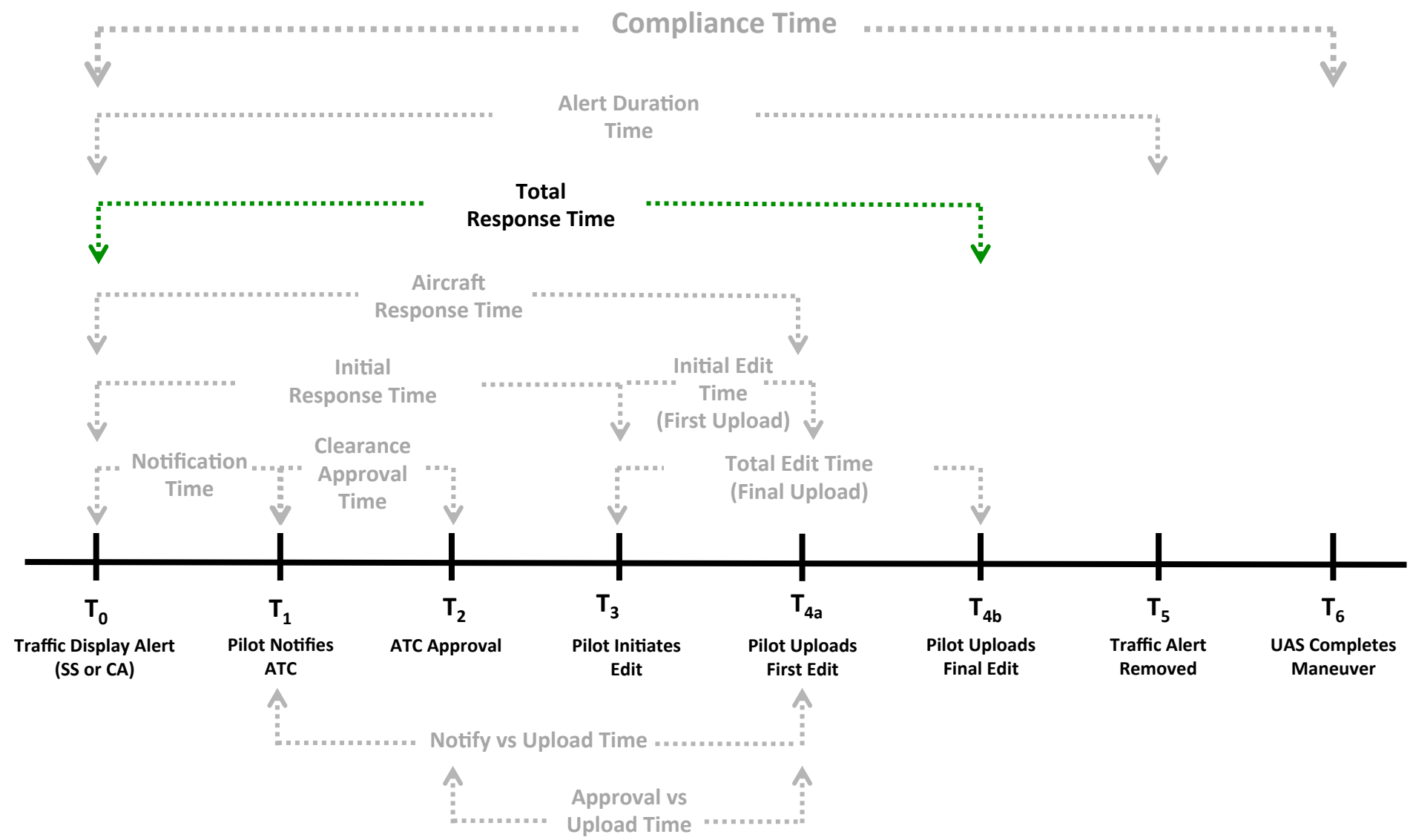
- Total Number of Encounters:
  - 282 encounters analyzed in following measured response data
    - 37 (13%) encounters were excluded due to pilot maneuvering prior to receiving an alert
- By Threat Level
  - 244 Corrective SS Alerts issued
  - 111 SS Warning Alerts issued
- By Intruder Equipage
  - 138 encounters with Cooperative Traffic
  - 144 encounters with Non-Cooperative Traffic

Measured Response Timeline & Associated Metrics

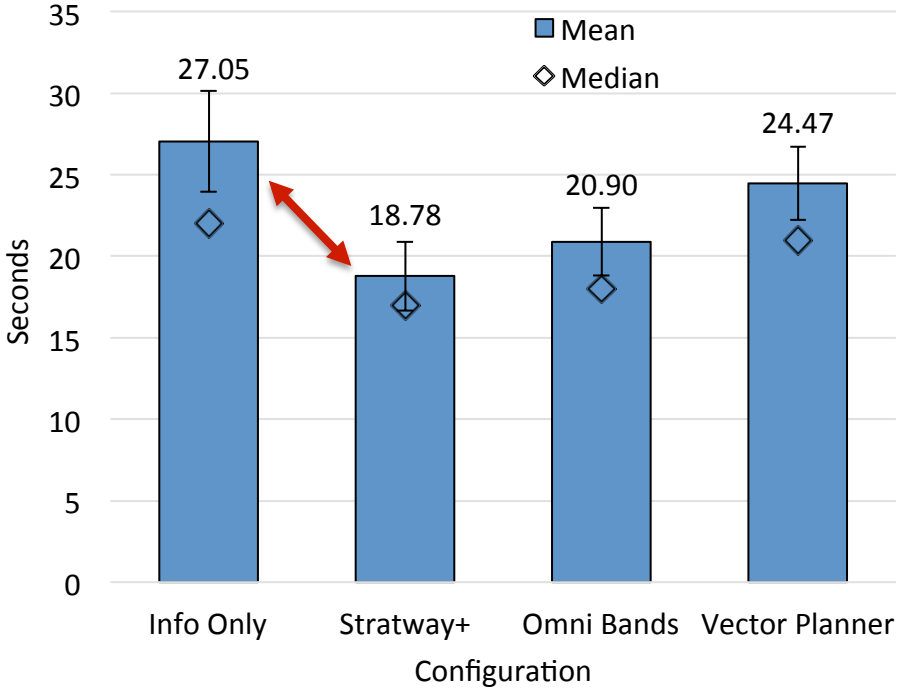


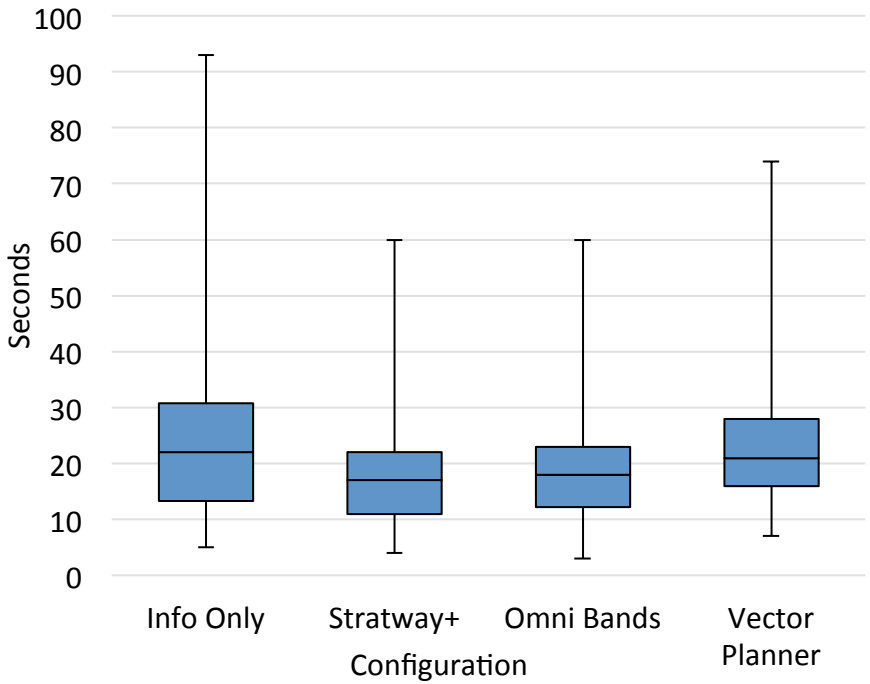
All metrics have been analyzed by: Display Type, Intruder Equipage, Sensor Model, and Threat Type

Measured Response Timeline & Associated Metrics



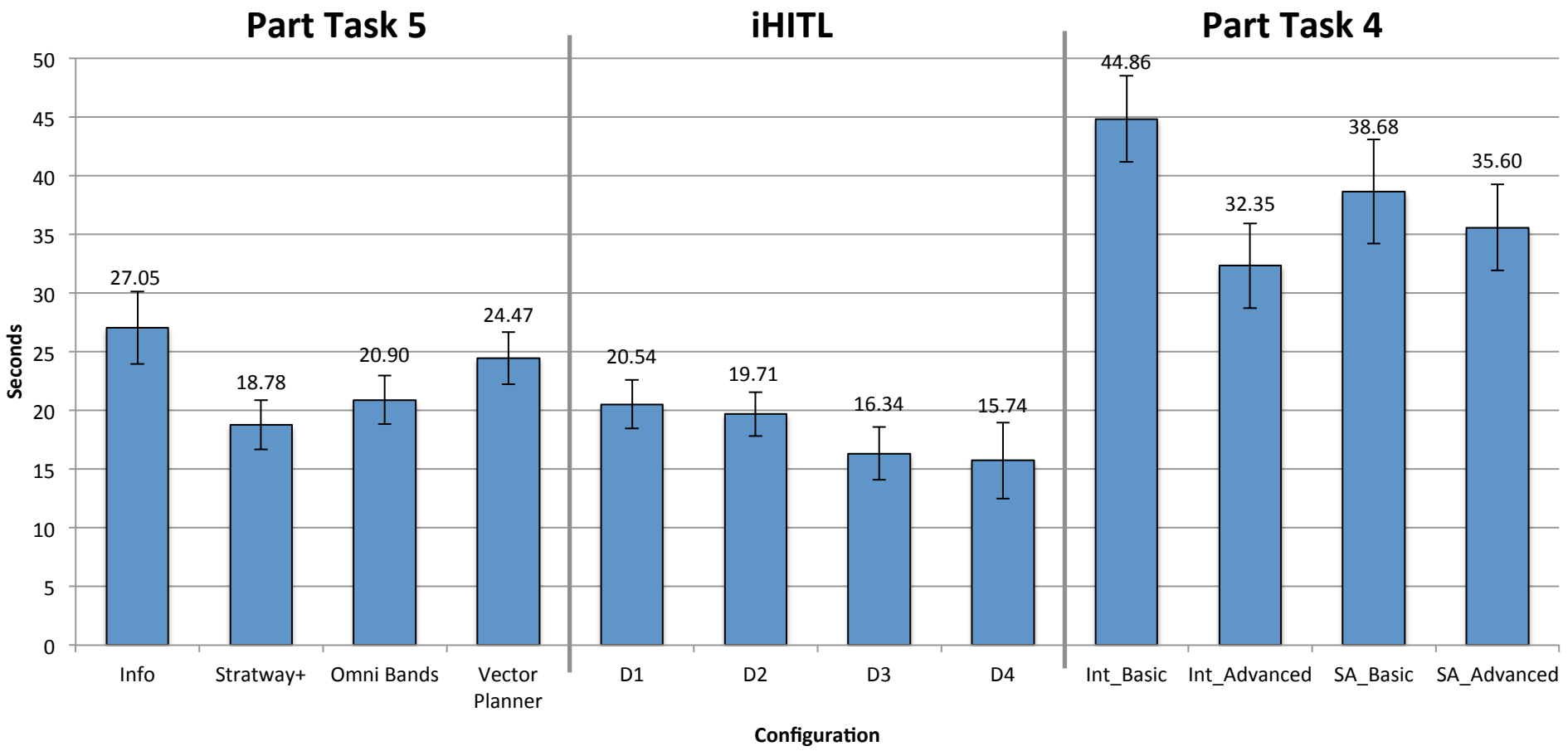
Total Response Time



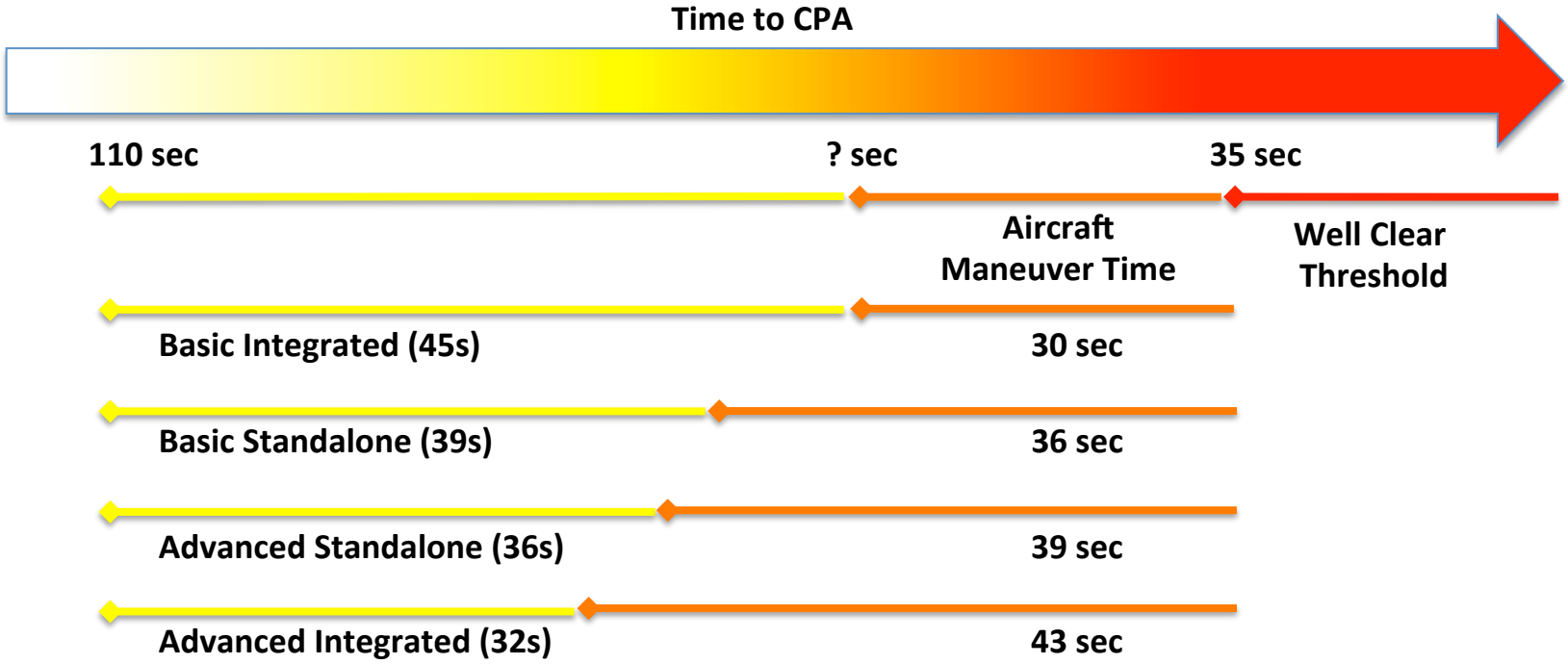


- Configuration had a significant effect on Total RTs:
  - Total RTs for Stratway+ were **8.2s** shorter, on average, than those in Info Only, a significant difference (p=0.02)
  - No other configurations differed significantly
- On average, pilots took **22.8s** to upload a final maneuver following the onset of a Corrective SS or SS Warning alert
  - 50% within 19s, 90% within 42s

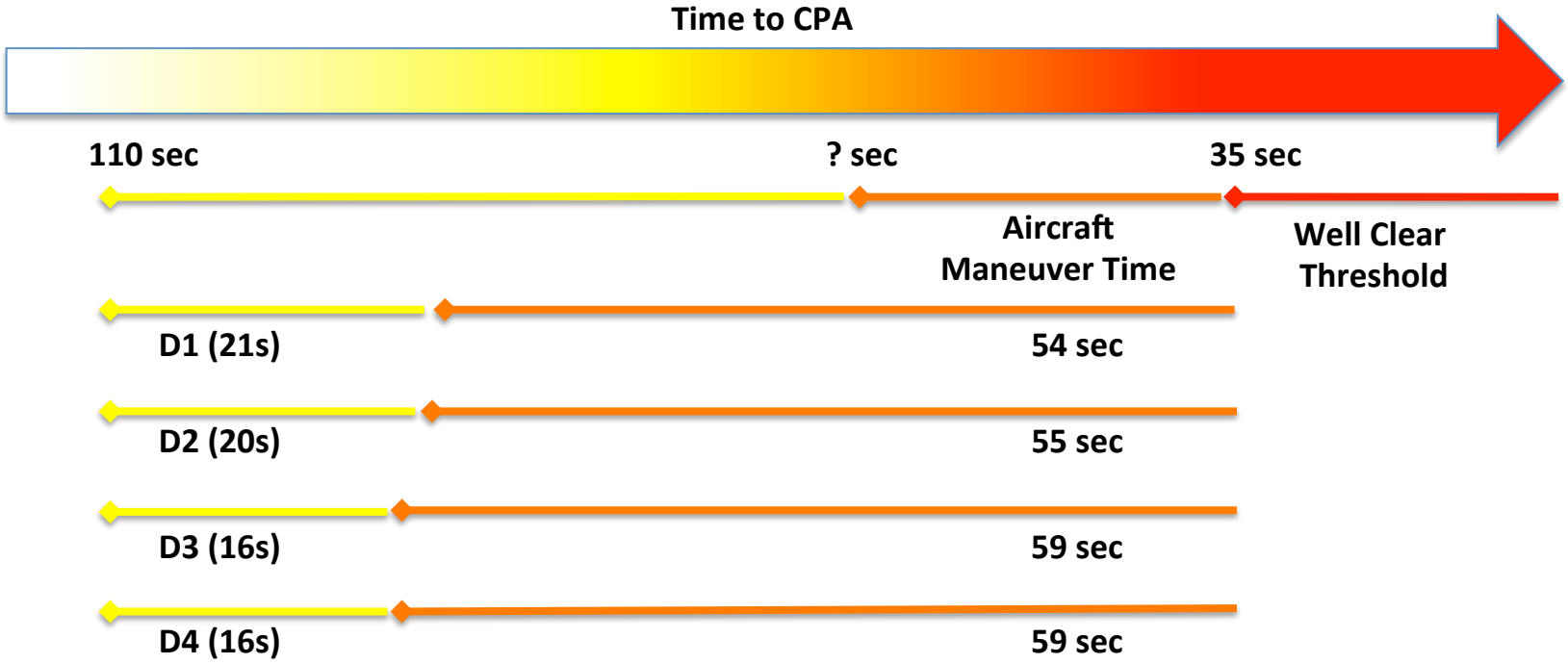
Total Response Times Across Simulations



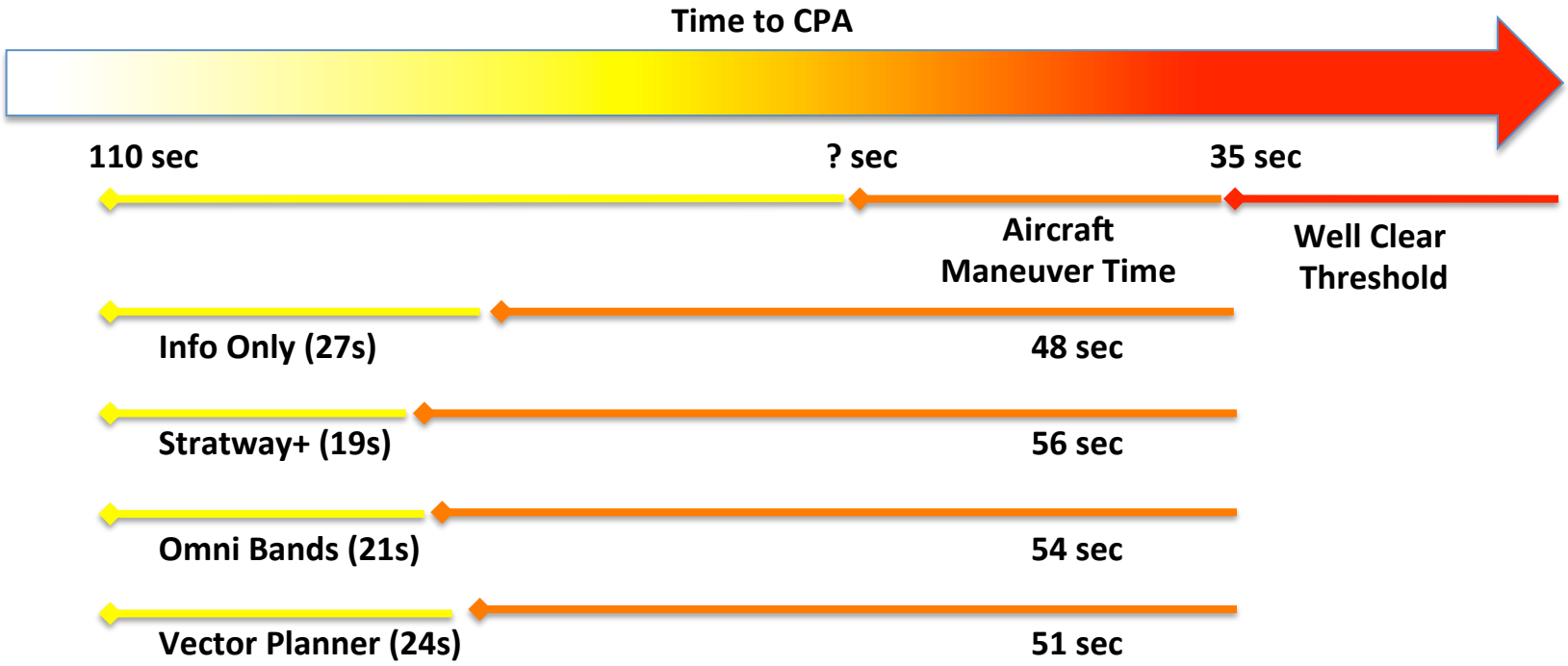
PT4 – Total Response Times



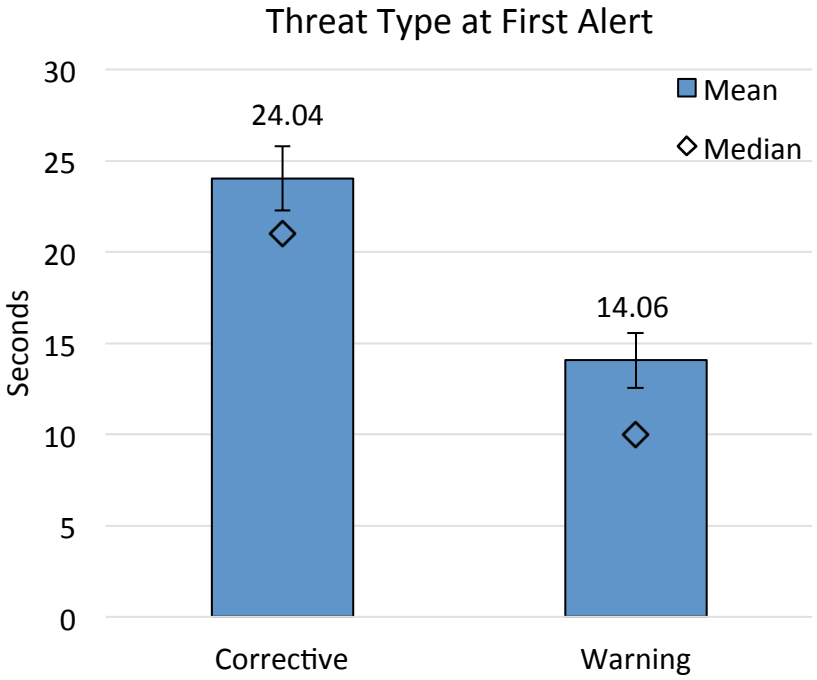
iHITL – Total Response Times

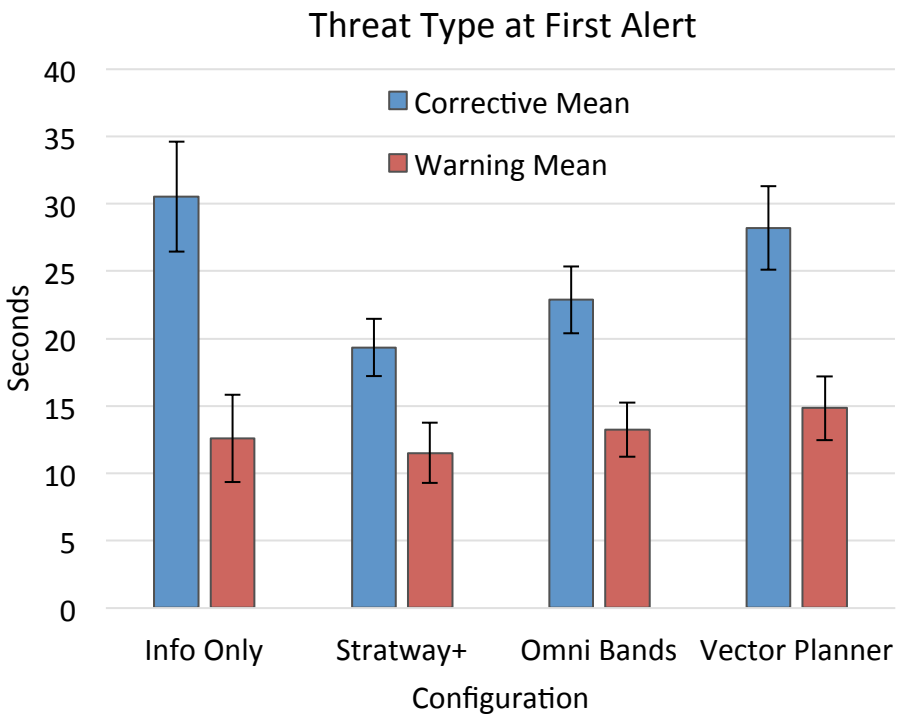


PT5 – Total Response Times



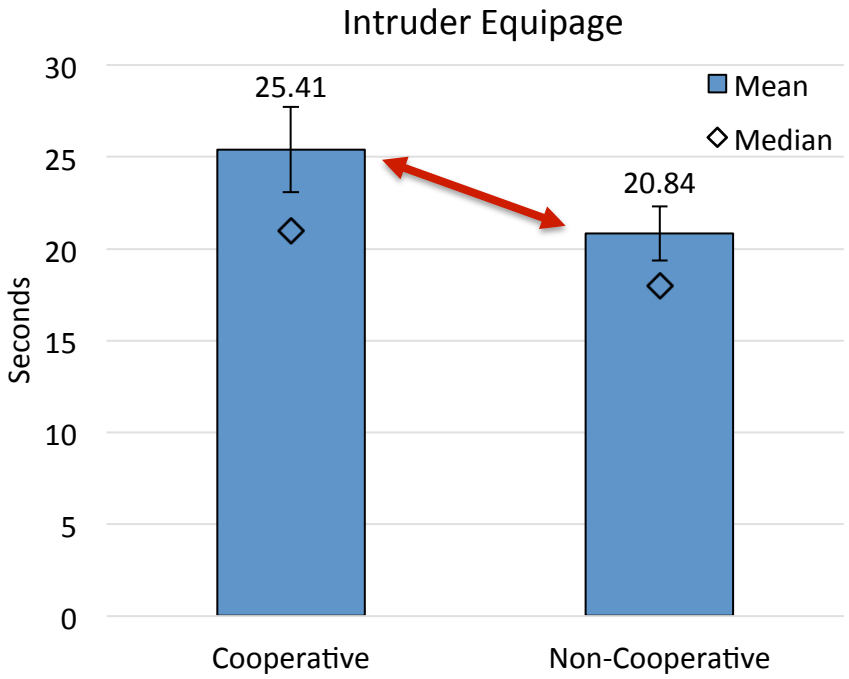
Total Response Time

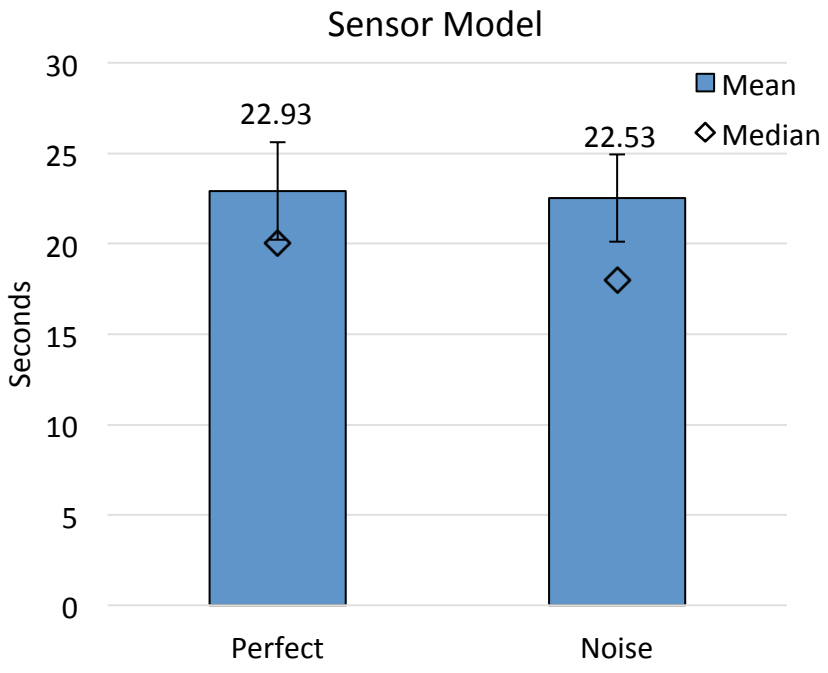




- Pilots responded, on average, **10s** faster to SS Warning Alerts than they did to Corrective SS Alerts
  - Pilots exhibited less variability between displays when responding to SS Warning Alerts than to Corrective SS Alerts
    - Range for SS Warning Alerts: 11s - 15s
    - Range for Corrective SS Alerts: 19s – 30s

Total Response Time



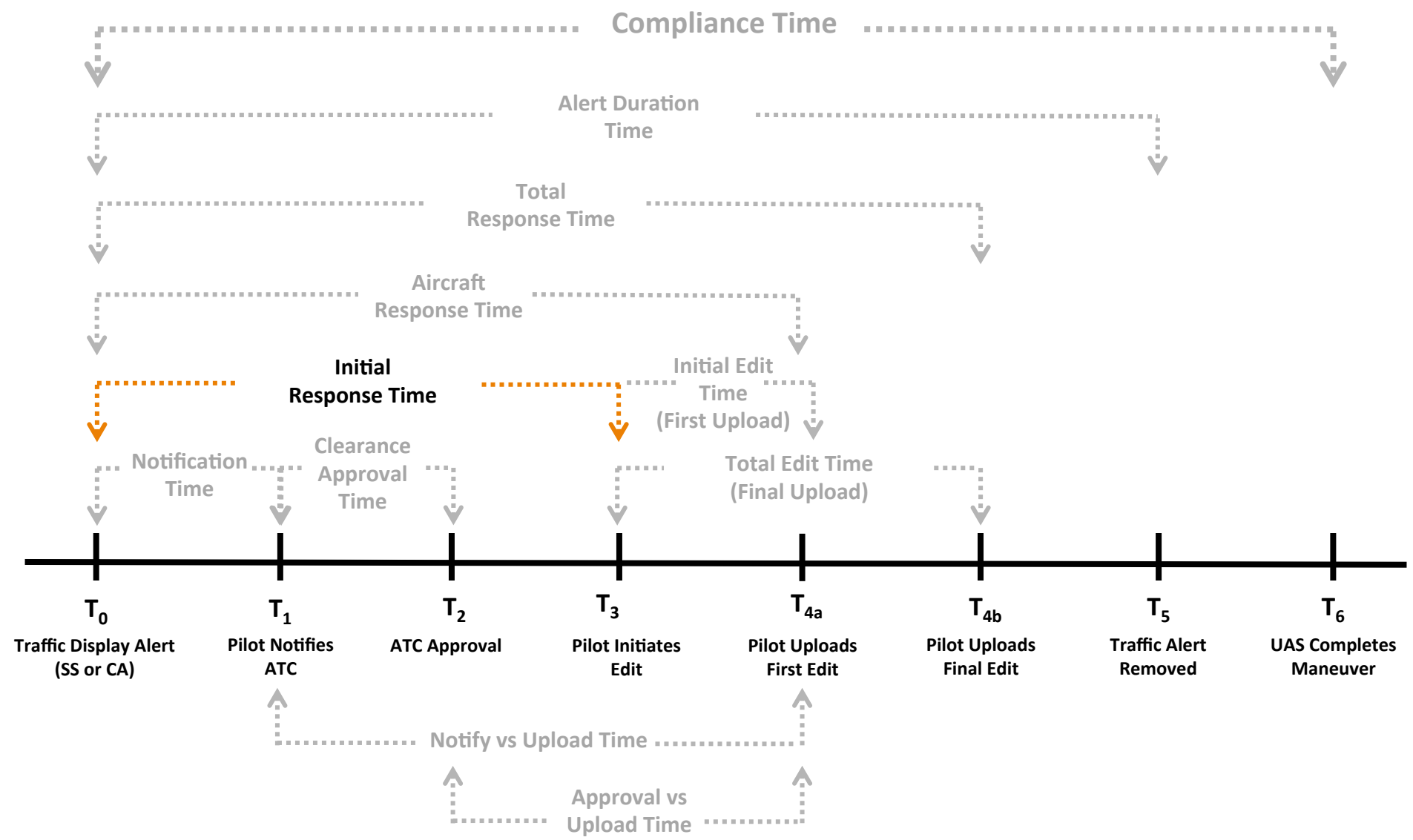


- Pilots responded, on average, **4.5s** faster to non-cooperative traffic than they did to cooperative traffic, which was a significant difference (p=.008)
  - There was also less variability in pilots' responses to Non-Cooperative encounters
- Sensor model was not found to have any effect on pilot's Total RTs

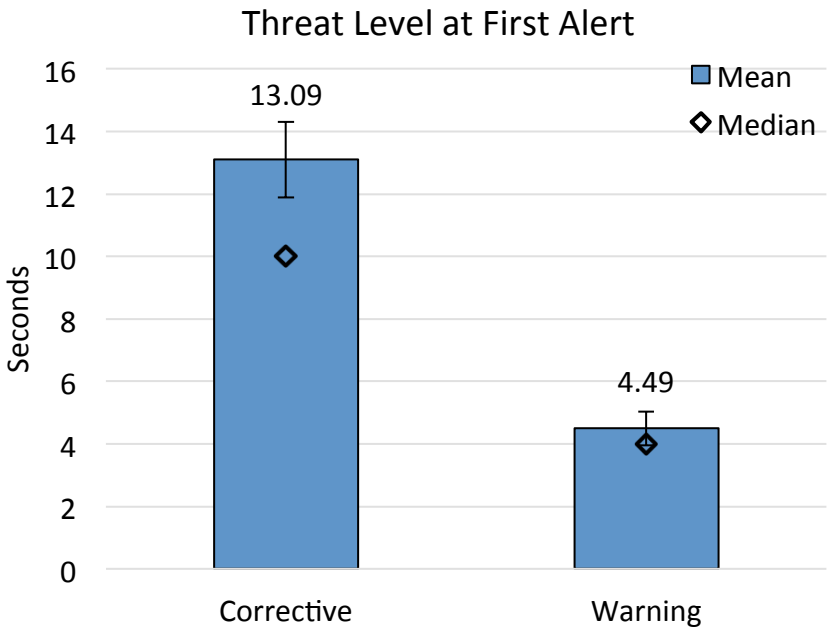
Question 4:

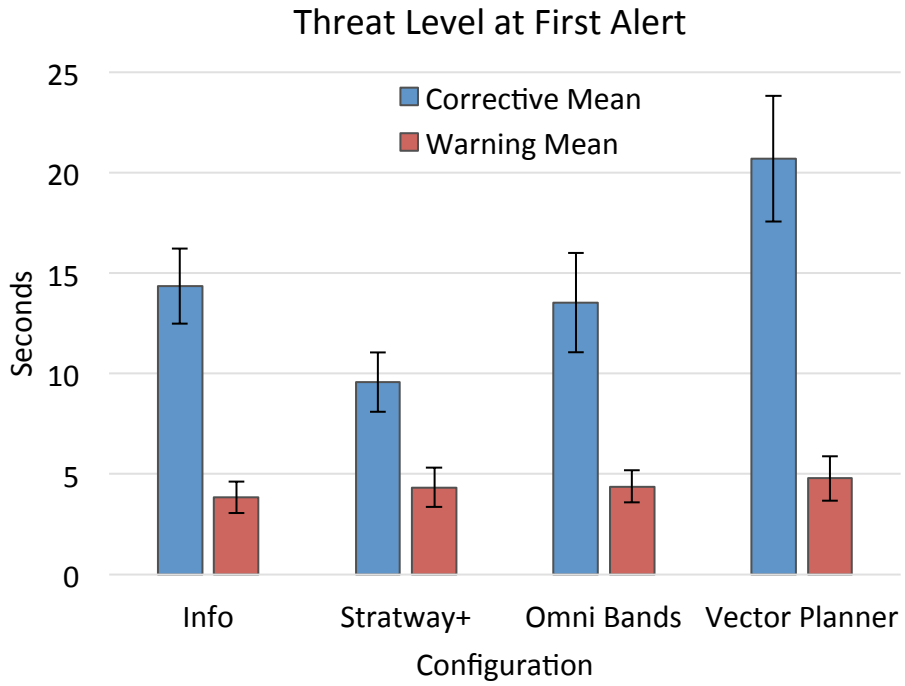
DID PILOTS DIFFER IN THEIR INITIAL RESPONSE TO ENCOUNTERS BASED ON THREAT LEVEL?

Measured Response Timeline & Associated Metrics



Initial Response Time





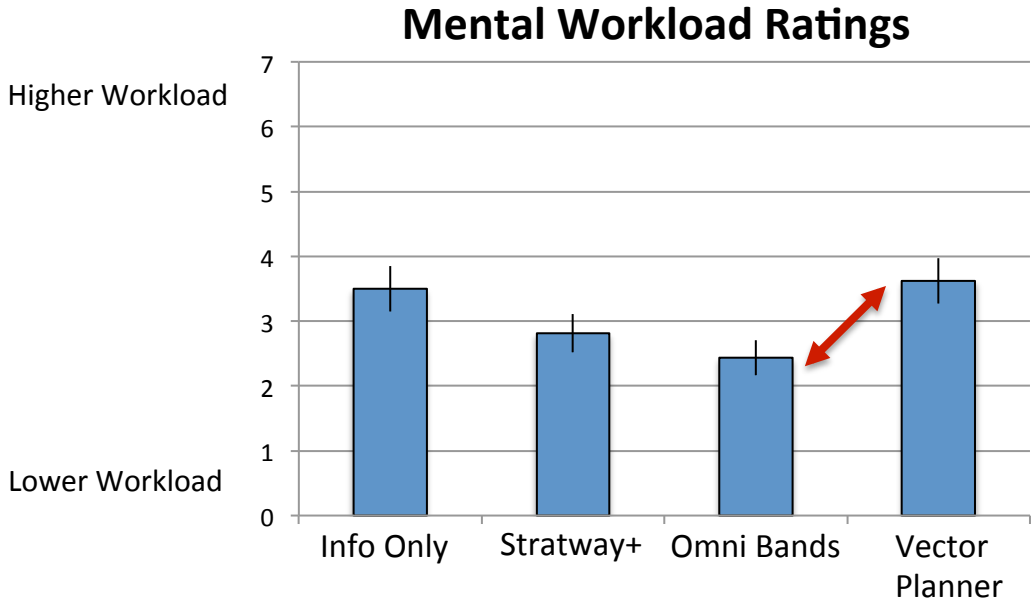
- Pilots, on average, initiated their edit **8.6s** faster in response to SS Warning Alerts than they did to Corrective SS Alerts
  - There was also less variability in general and between displays when pilots were responding to SS Warning Alerts
  - Pilots responding to SS Warning Alerts within 5s in all four displays

SUBJECTIVE DATA

- Workload Ratings (by Display)
- Post-Trial Response (by Display)
- Post-Sim Response (by Additional Variables)

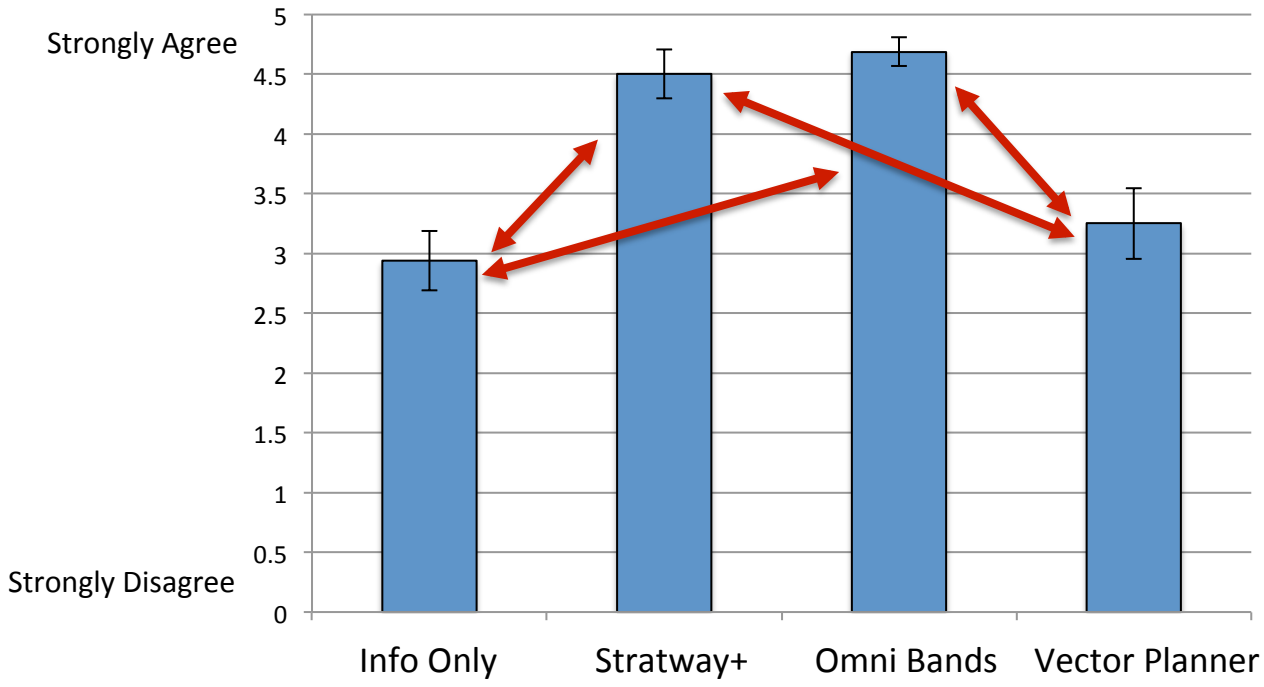
Workload

- Omni Bands (D3) resulted in significantly lower workload ratings than the Vector Planner (D4) for 5 of the 6 scales:
  - Mental, Temporal, Effort, Frustration, & Performance Degradation
    - Only Physical Demands failed to result in a significant difference
  - Stratway+ and Omni Bands were never rated as significantly different



Post-Trial

- Did the display provide the necessary information to perform a maneuver for separation?
  - Stratway+ and Omni Bands were rated as significantly better at providing sufficient information



Post-Sim & Debrief

- All 3 alert levels were rated favorably by pilots
  - Overwhelmingly agreed *visual display* of alerts were easy to understand and distinct
  - Agreed that *auditory alerts* were easy to distinguish and useful
  - Reported that the timing of the alerts were appropriate
- Information level
  - Pilots generally agreed that they had all the information needed to perform the task
  - Several commented that a dead-reckoning line or 'history trail' would be useful

Summary

- Suggestive Guidance:
  - Suggestive guidance in the form of banding resulted in ***safer*** and ***more timely*** maneuvers away from conflicts
    - Fewer overall number of LoWC for both banding displays
      - Pilots responsible for significantly fewer (75% fewer) LoWC
    - Less severe LoWC for both banding displays
      - No instance of intruder penetrating more than 40% of the well clear threshold for Stratway or Omni Bands
    - Shorter Total RTs for both banding displays
      - Stratway+ was significantly shorter than Info Only but both banding displays showed quick responses
    - Pilots self-report as preferring the banding displays
      - Pilots reported that Omni Bands significantly reduced pilot workload relative to Vector Planner, but both banding displays showed lower workload ratings in general that Info Only and Vector Planner
      - Both banding displays were judged to provide valuable information not present in the other conditions

Summary

- Alerting Logic:
  - Subjective feedback was overwhelmingly positive
    - Visual and auditory features were rated highly
    - Pilots understood the alerting structure with no suggested changes
  - SS Warning alert resulted in pilots more quickly uploading a maneuver to the aircraft with less variation between displays (by 10s)
- Categorization of LoWC
  - The categories of LoWC developed here revealed several sources of LoWC not previously considered:
    - Numerous LoWC occurred when ownship and threat were diverging
    - Numerous LoWC also occurred due to the pilot returning to route too soon

	Ineffective Maneuver	Too Slow	Too Early	Diverging LoWC	Total
Info Only	8	0	4	4	**16**
Stratway+	2	1	2	0	**5**
Omni Bands	0	0	0	3	**3**
Vector Planner	3	2	1	2	**8**
Total	**13**	**3**	**7**	**9**	

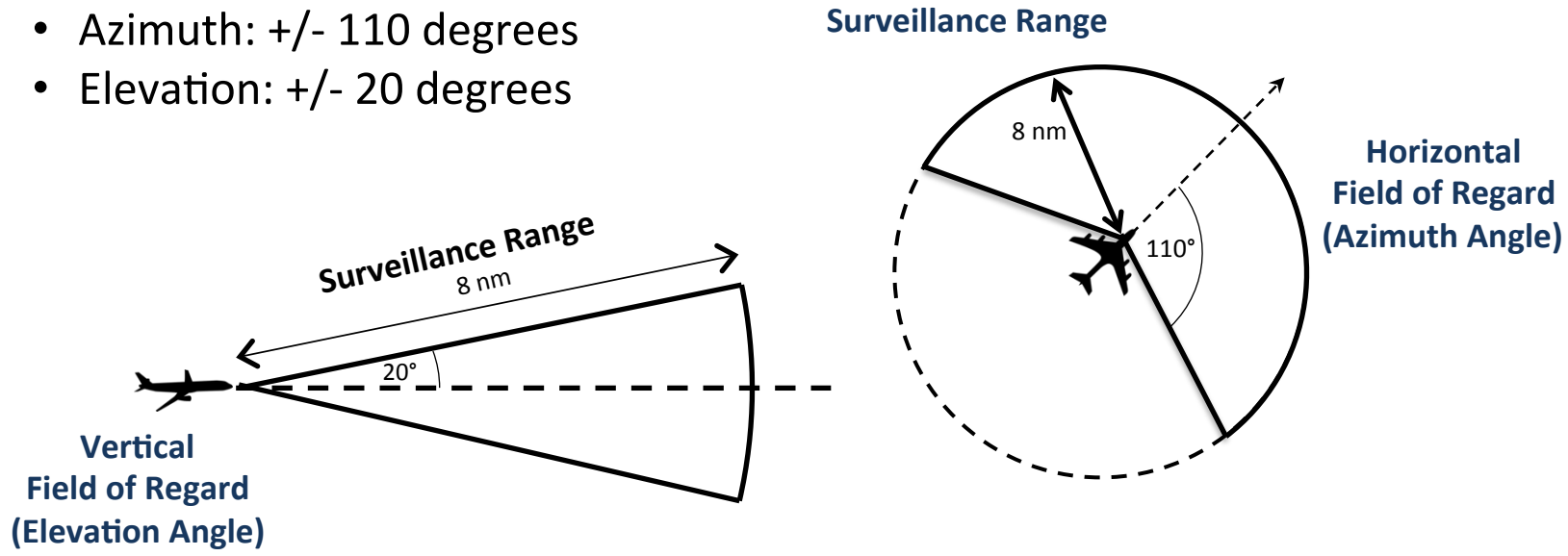
Going Forward

- Flight Test 3 (presented by Debra yesterday)
  - Use flight test environment to verify the results we saw in PT5
    - Flying surrogate aircraft
  - Brining 2 displays from PT5
    - Information Only
    - Omni Bands

BACK UP SLIDES

Alerting Logic

- Sensor Ranges
  - Simulated **cooperative** sensor: ADS-R/TCAS-like ranges
    - Lateral Range: 15 nm
    - Vertical Range: +/- 5000 ft
  - Simulated **non-cooperative** sensor: based on state-of-the-art airborne RADAR
    - Lateral Range: 8 nm
    - Azimuth: +/- 110 degrees
    - Elevation: +/- 20 degrees



Parameters for Noisy Cooperative Sensor

Noisy Cooperative Sensor ("Transponder")			
	Parameter	**Value**	**Unit**
Field Of Regard	Range	15	nmi
	Azimuth	360	deg
	Elevation	+/-90	deg
Accuracy	Range Error Mean	0	nmi
	Range Error Std. Dev	0	nmi
	Range Moving Avg. Window Size	1	measures
	Azimuth Error Mean	0	deg
	Azimuth Error Std. Dev	2	deg
	Azimuth Moving Avg. Window Size	3	measures
	Altitude Quantization	100	feet
	Altitude Moving Avg. Window	6	measure

Yellow denotes the noise model variables that will used for PT5.

Parameters for Noisy Non-Cooperative Sensor

Noisy Non-Cooperative Sensor ("Airborne Radar")			
	Parameter	**Value**	**Unit**
Field Of Regard	Range	6	nmi
	Azimuth	+/-110	deg
	Elevation	+/-20	deg
Accuracy	Range Error Mean	0.008	nmi
	Range Error Std. Dev.	0.001	nmi
	Range Moving Avg. Window Size	1	measures
	Azimuth Error Mean	0	deg
	Azimuth Error Std. Dev.	2	deg
	Azimuth Moving Avg. Window Size	3	measures
	Elevation Error Mean	1	deg
	Elevation Error Std. Dev.	1	deg
	Elevation Moving Avg. Window Size	6	measure

Yellow denotes the noise model variables that will used for PT5.

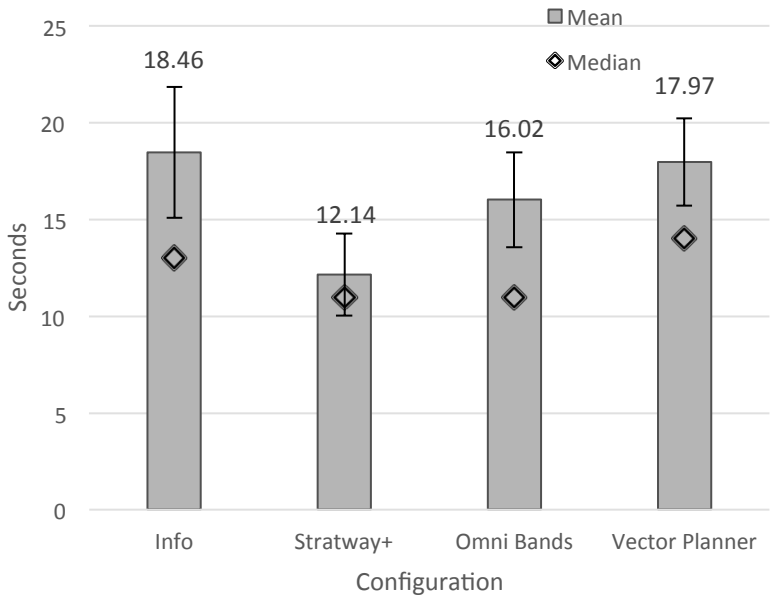
Parameters for “Perfect” Cooperative Sensor

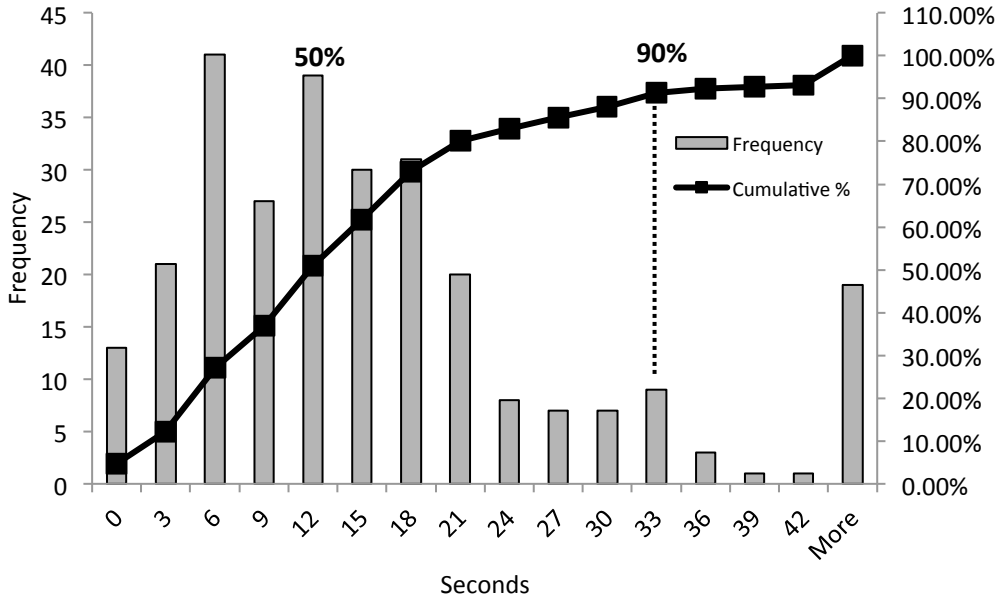
“Perfect” Cooperative Sensor (“ADS-B”)			
	Parameter	**Value**	**Unit**
Field Of Regard	Range	15	nmi
	Azimuth	360	deg
	Elevation	+/-90	deg
Accuracy	Latitude Error	0	deg
	Latitude Error Std. Dev.	0	deg
	Latitude Moving Avg. Window Size	1	measures
	Longitude Error	0	deg
	Longitude Error Std. Dev.	0	deg
	Longitude Moving Avg. Window Size	1	measures
	Altitude Error	0	deg
	Altitude Error Std. Dev.	0	deg
	Altitude Moving Avg. Window Size	1	measure

Parameters for “Perfect” Non-Cooperative Sensor

“Perfect” Non-Cooperative Sensor (“Perfect Airborne Radar”)			
	Parameter	**Value**	**Unit**
Field Of Regard	Range	6	nmi
	Azimuth	+/-110	deg
	Elevation	+/-20	deg
Accuracy	Range Error Mean	0	nmi
	Range Error Std. Dev.	0	nmi
	Range Moving Avg. Window Size	1	measures
	Azimuth Error Mean	0	deg
	Azimuth Error Std. Dev.	0	deg
	Azimuth Moving Avg. Window Size	1	measures
	Elevation Error Mean	0	deg
	Elevation Error Std. Dev.	0	deg
	Elevation Moving Avg. Window Size	1	measure

Notify Time

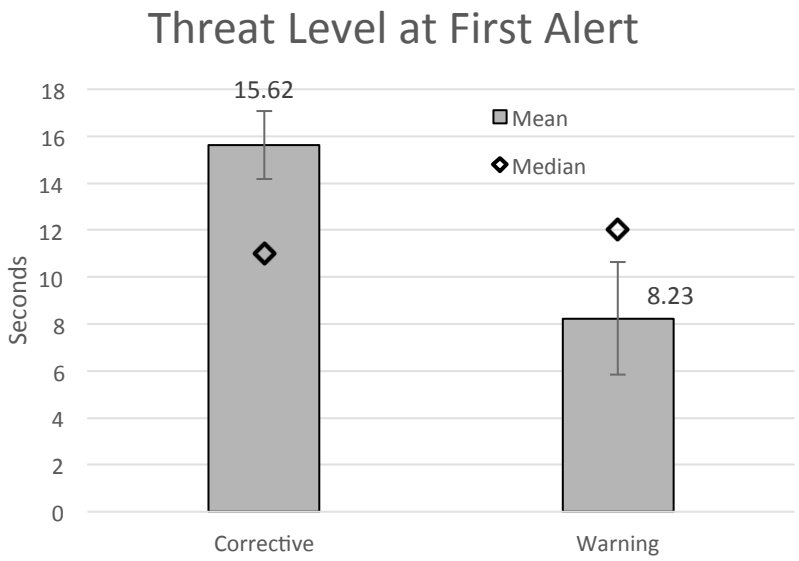


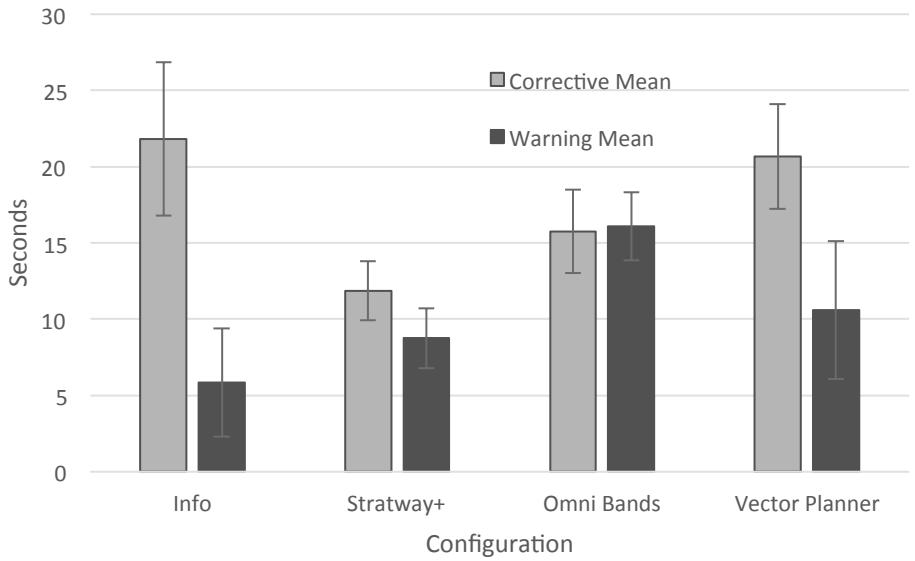


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots took an overall average of **16.15 seconds** to notify ATC in response to a Corrective SS or SS Warning alert
  - Median = 12 seconds

- 50% of pilots notified ATC within **12 seconds** of the onset of the alert
- 90% of pilots notified ATC within **33 seconds** of the onset of the alert

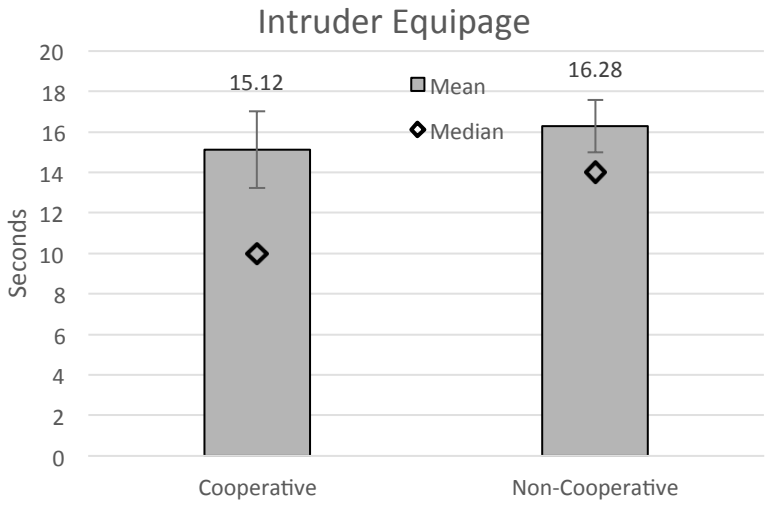
Notify Time

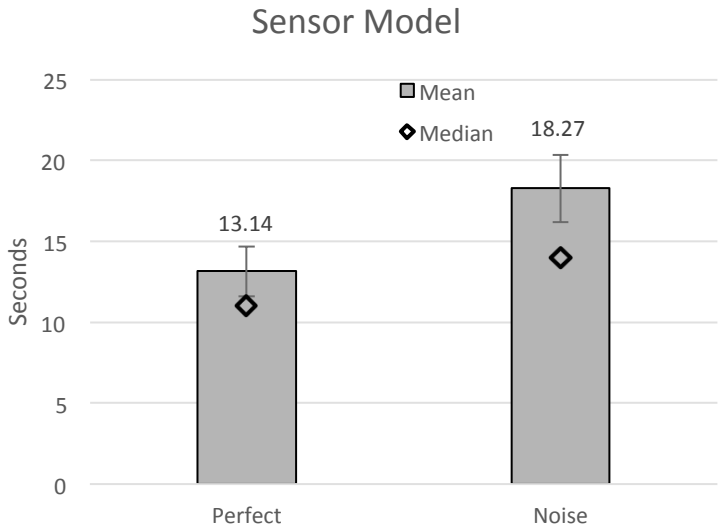




- Pilots on average notified ATC **7.39 seconds** faster following an SS Warning alert than a Corrective SS alert
  - Median Difference = 1 second faster in response to Corrective SS alert
- Unable to test for significant interaction
  - Much larger differences between Corrective Notify times and Warning Notify times for D1 and D4

Notify Time



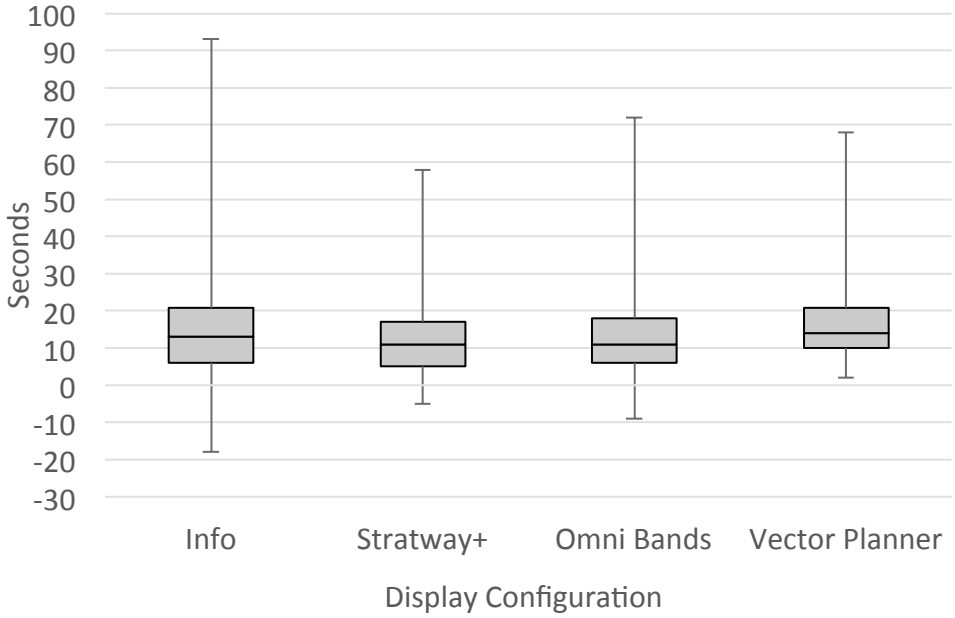


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average notified ATC **1.16 seconds** faster in response to alerts to cooperative aircraft
  - Median Difference = 4 seconds faster in response to cooperative traffic

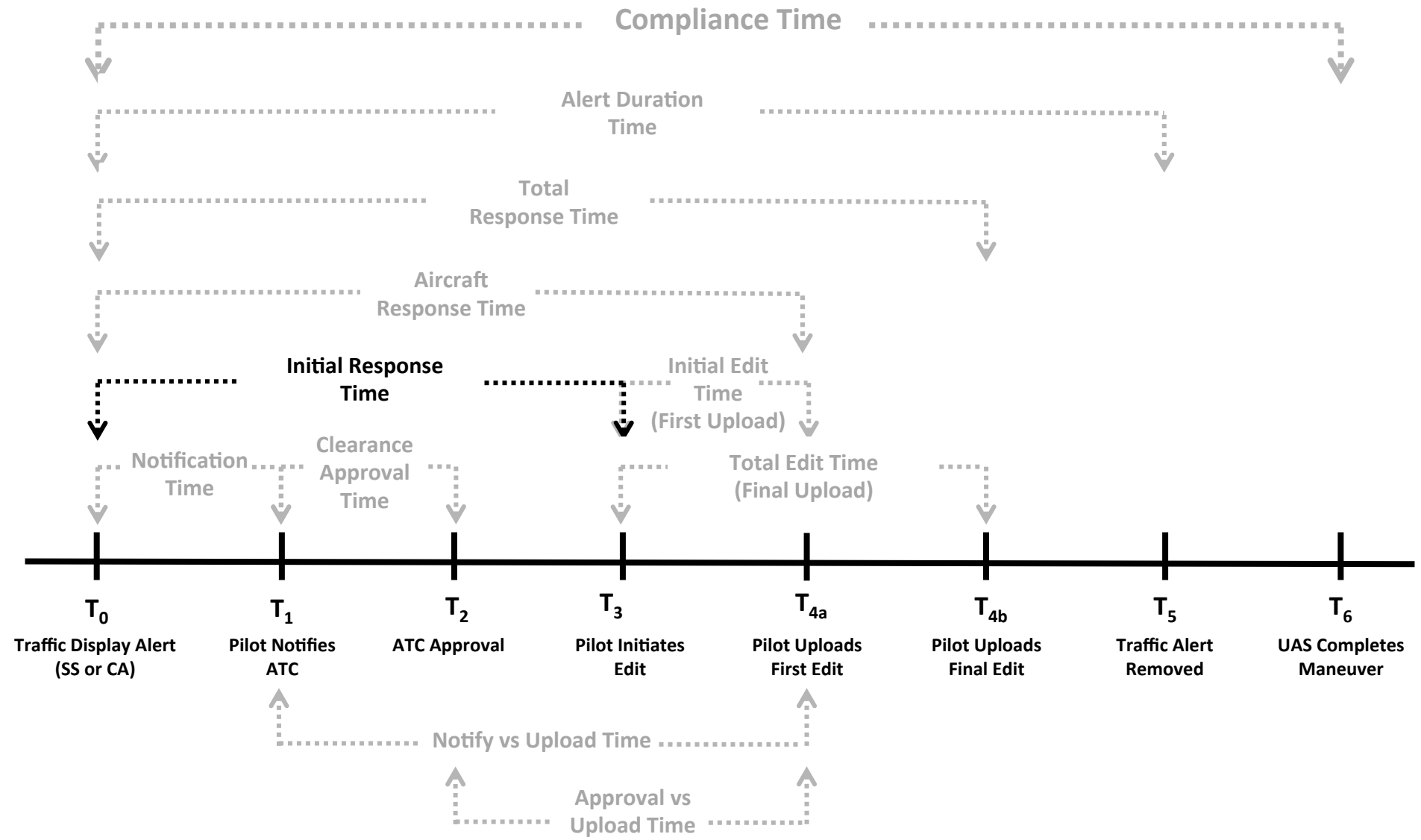
- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average notified ATC **5.13 seconds** faster in the perfect sensor model condition
  - Median Difference = 3 seconds faster in perfect sensor model condition

Notify Time

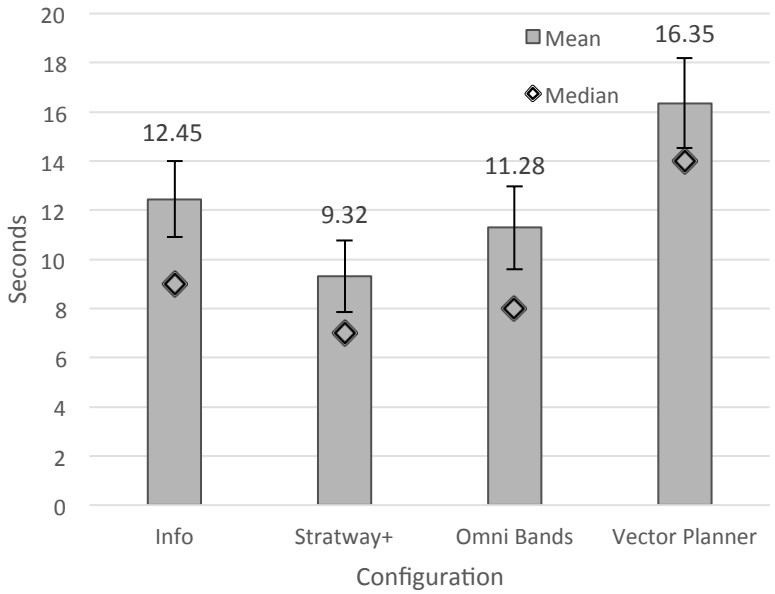
	D1	D2	D3	D4
Min	-18	-5	-9	2
Q1	6	5	6	10
Median	13	11	11	14
Q3	20.75	17	18	20.75
Max	93	58	72	68

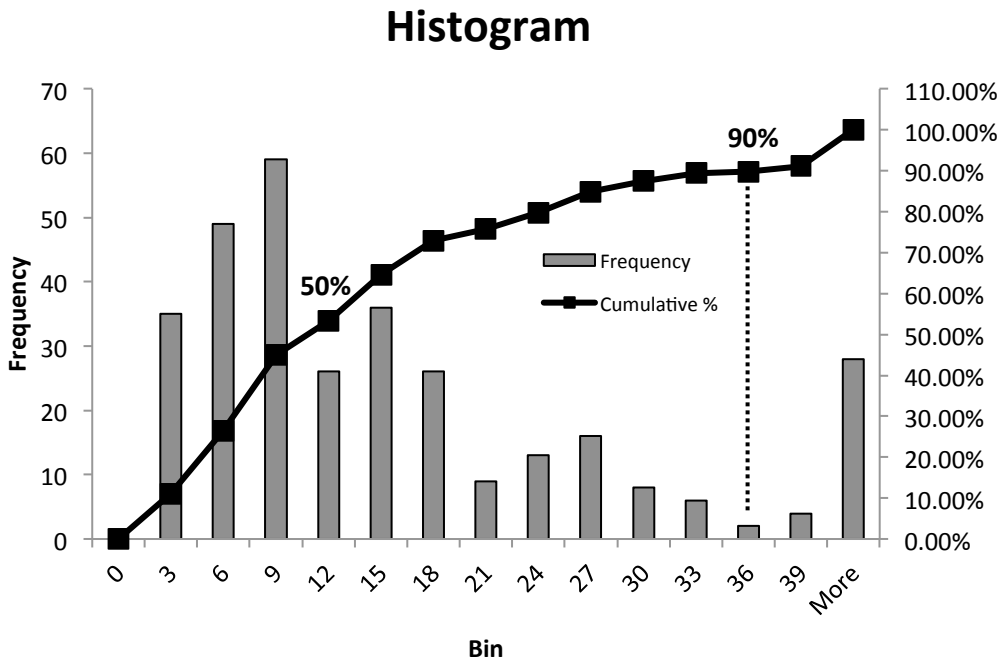


Stages of Pilot DAA Task



Initial Response Time

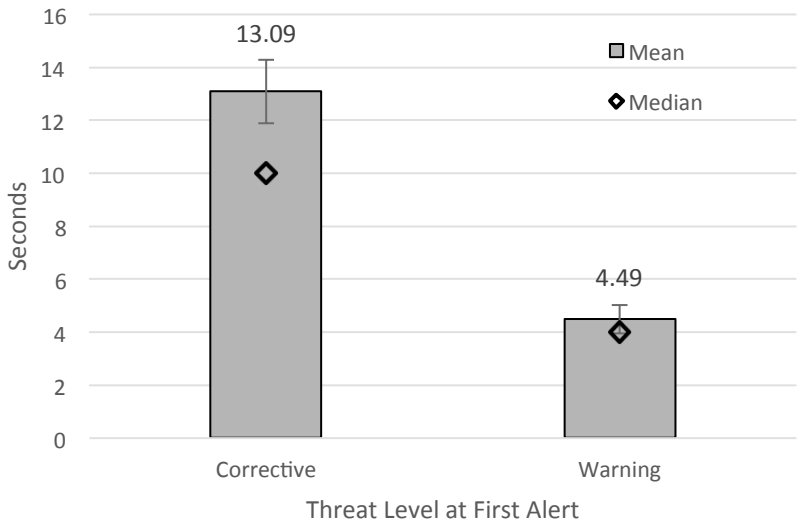


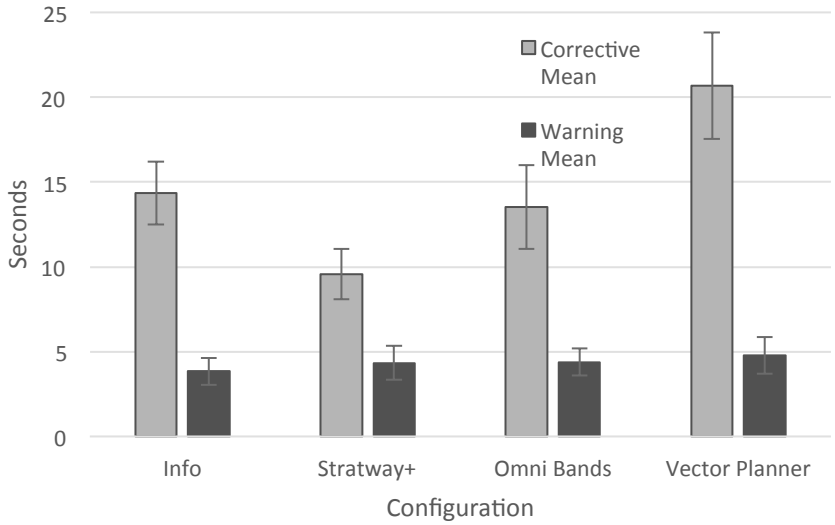


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots took an overall average of **12.35 seconds** to initiate an edit in response to a Corrective SS or SS Warning alert
  - Median = 9 seconds

- 50% of pilots initiated an edit within **12 seconds** of the onset of the alert
- 90% of pilots initiated an edit within **36 seconds** of the onset of the alert

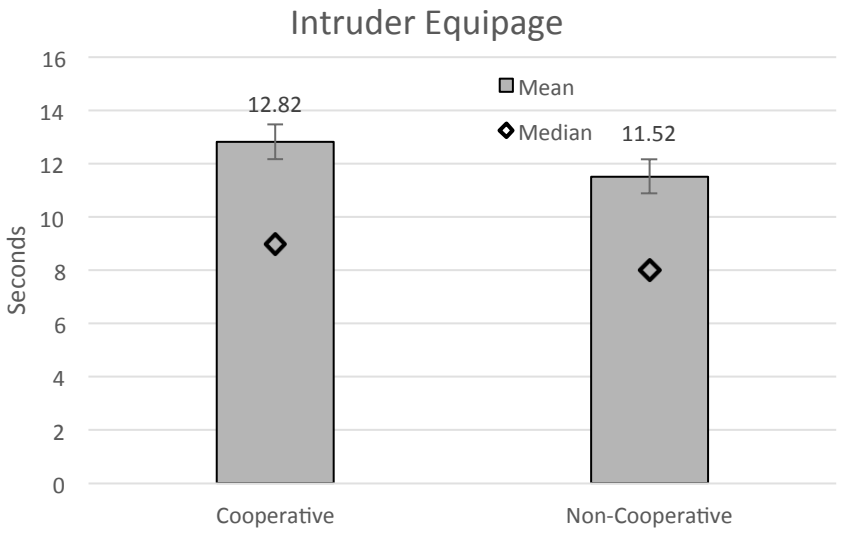
Initial Response Time

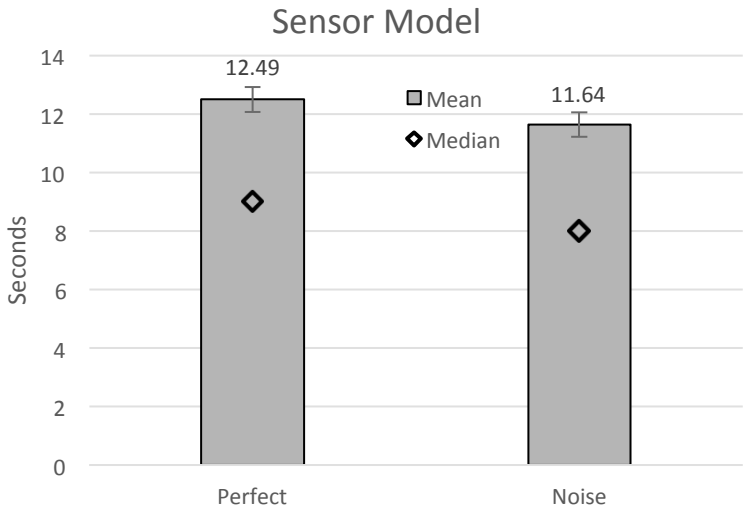




- Pilots on average initiated an edit **8.60 seconds** faster following an SS Warning alert than a Corrective SS alert
  - Median Difference = 6 second faster in response to an SS Warning alert
- Unable to test for significant interaction
  - Large differences between Corrective and Warning Initial RTs for all configurations

Initial Response Time



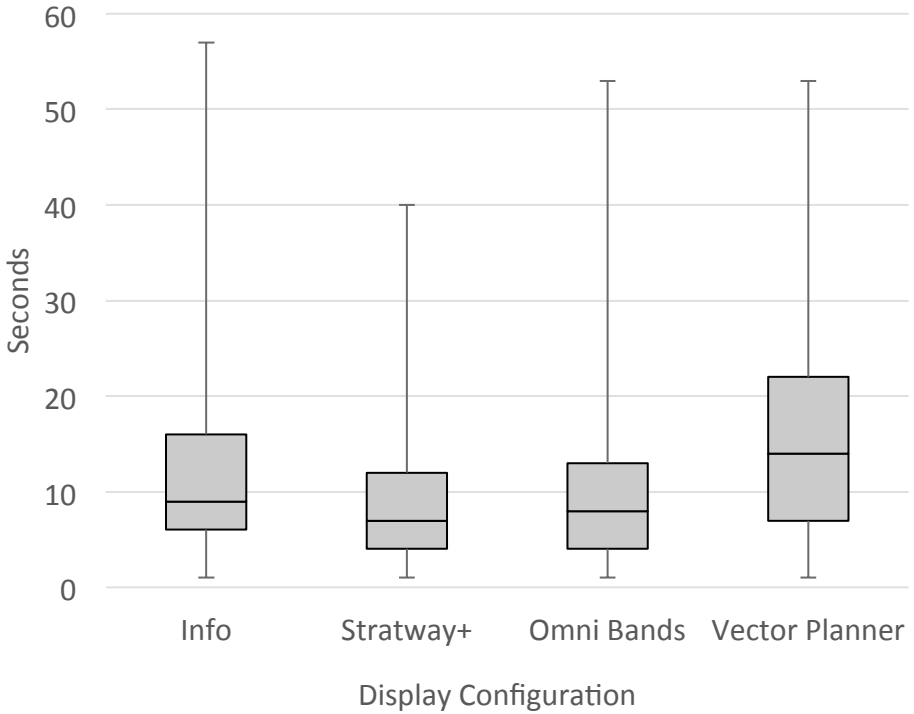


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average initiated an edit **1.30 seconds** faster in response to alerts to non-cooperative aircraft
  - Median Difference = 1 seconds faster in response to non-cooperative traffic

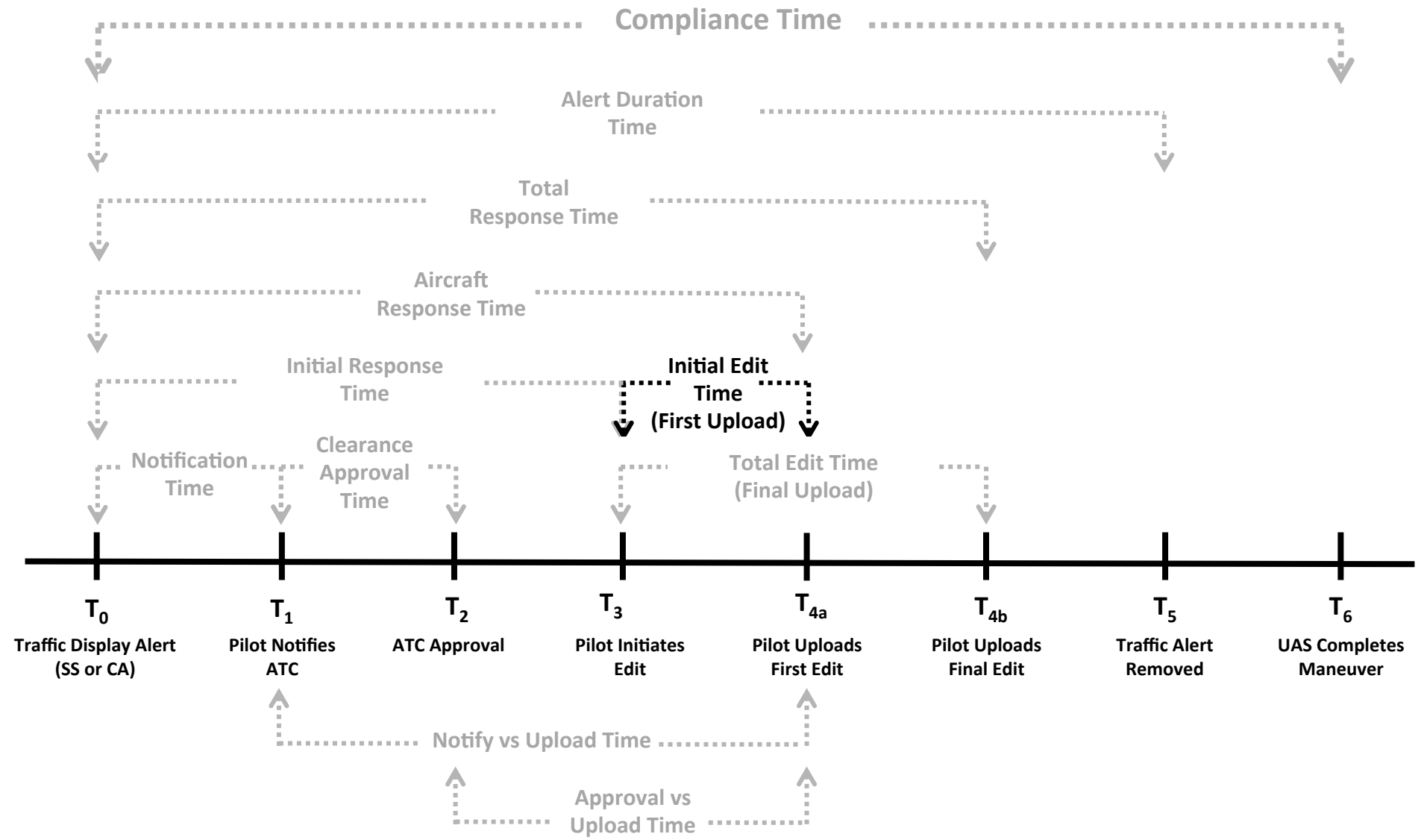
- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average initiated an edit **0.85 seconds** faster in the noisy sensor model condition
  - Median Difference = 1 seconds faster in the noisy sensor model condition

Initial Response Time

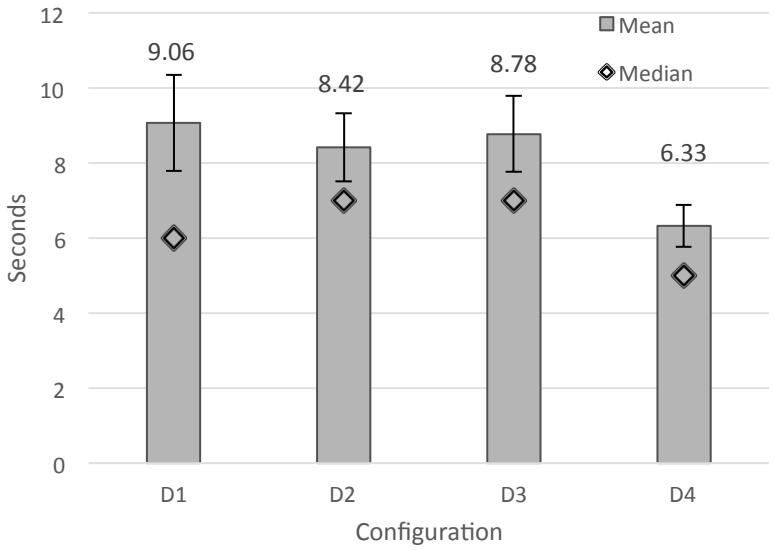
	D1	D2	D3	D4
Min	1	1	1	1
Q1	6	4	4	7
Median	9	7	8	14
Q3	16	12	13	22
Max	57	40	53	53

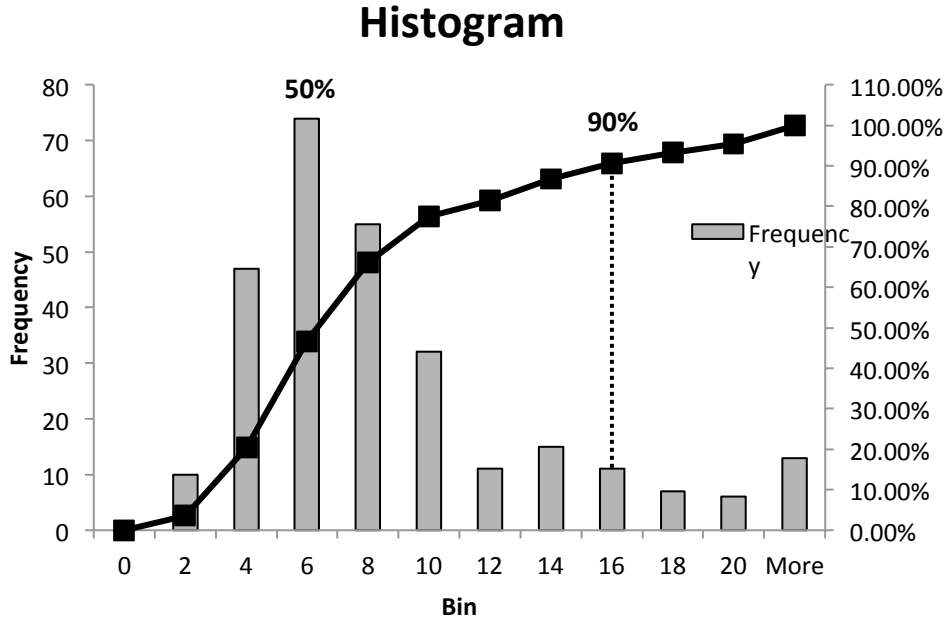


Stages of Pilot DAA Task



Initial Edit Time

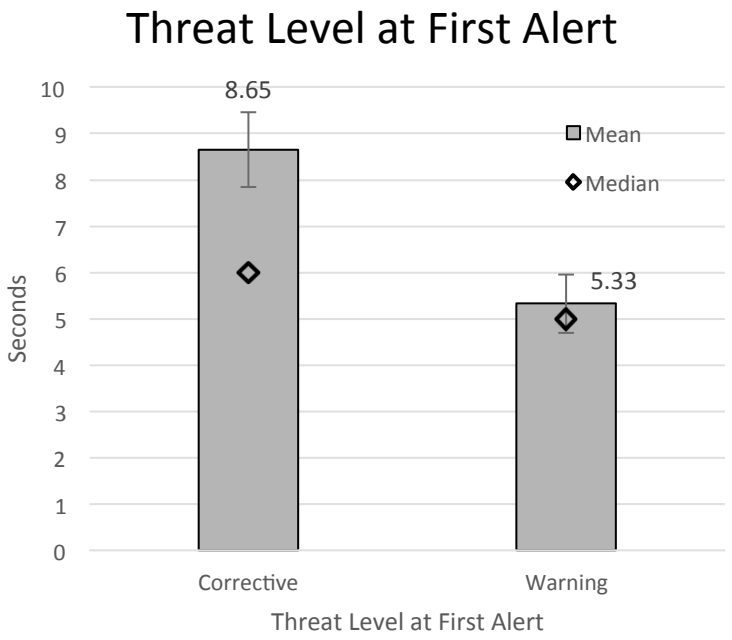


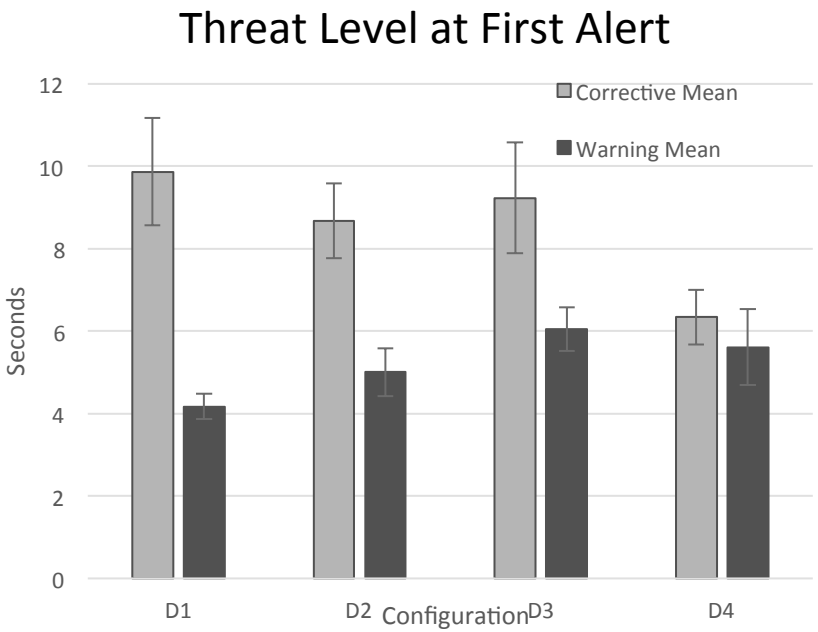


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots took an overall average of **8 seconds** to make an initial edit to a Corrective SS or SS Warning alert
  - Median = 6 seconds

- ➢ 50% of pilots notified ATC within **6 seconds** of the onset of the alert
- ➢ 90% of pilots notified ATC within **16 seconds** of the onset of the alert

Initial Edit Time



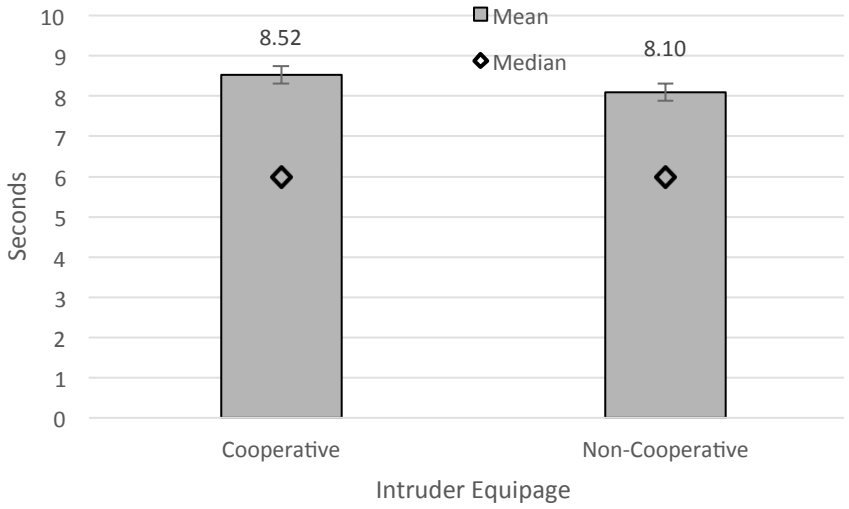


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average made initial edits **3.32 seconds** faster following an SS Warning alert than a Corrective SS alert
  - Median Difference = 1 second faster in response to SS Warning alert

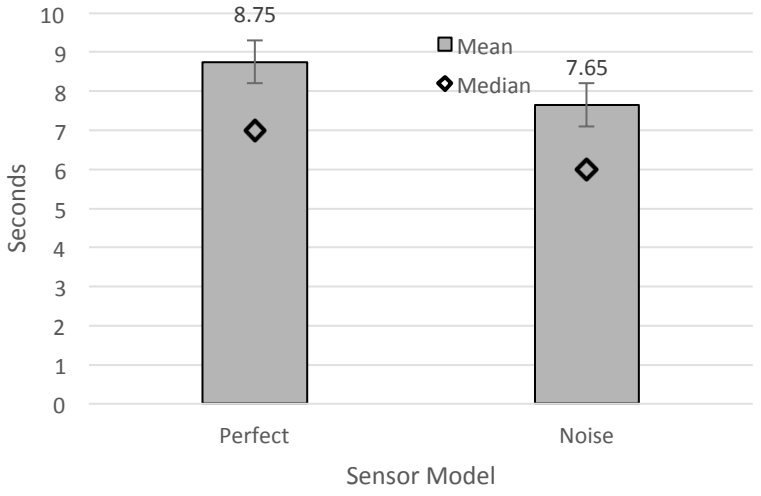
- Unable to test for significant interaction
  - ~~Much larger differences between Corrective Notify times and Warning Notify times for D1 and D4~~

Initial Edit Time

By Intruder Equipage



By Sensor Model

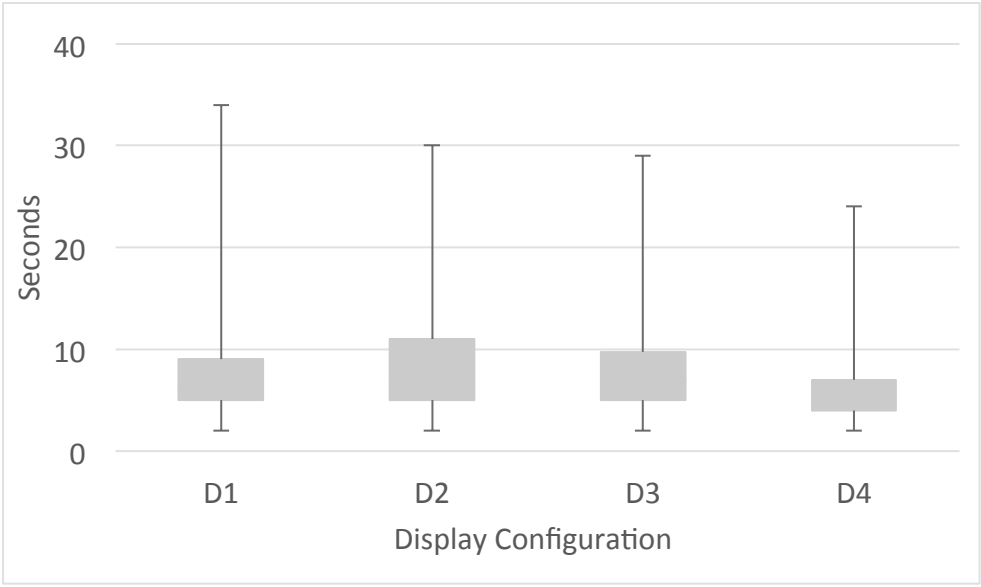


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average made initial edits **0.43 seconds** faster in response to alerts to non - cooperative aircraft
  - Median Difference = 0 seconds faster in response to non-cooperative traffic

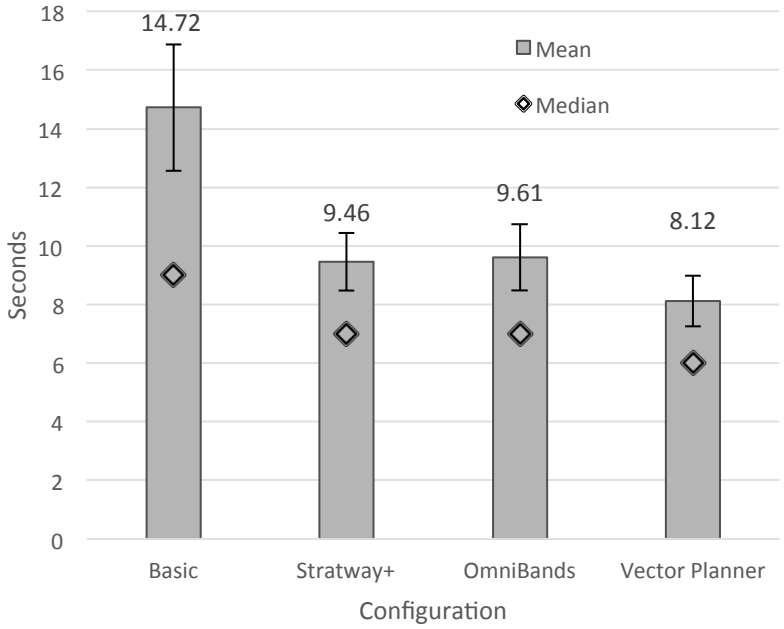
- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average made initial edits **1.10 seconds** faster in the noisy sensor model condition
  - Median Difference = 1 seconds faster in noisy sensor model condition

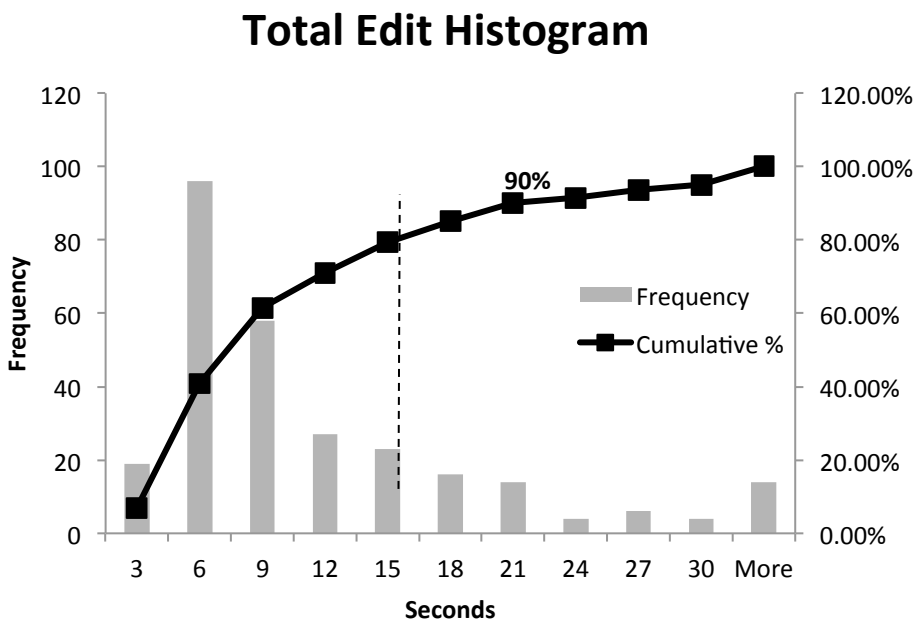
Initial Edit Time

	D1	D2	D3	D4
Min	2	2	2	2
Q1	5	5	5	4
Median	6	7	7	5
Q3	9	11	9.75	7
Max	34	30	29	24



Total Edit Time

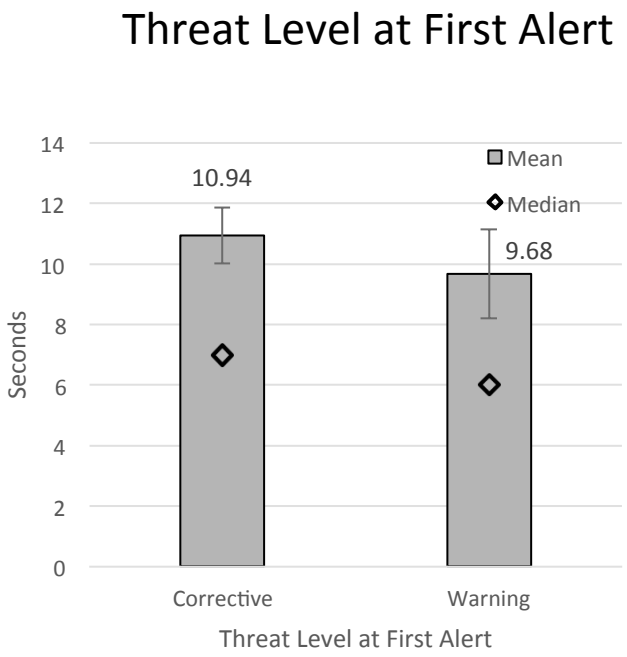


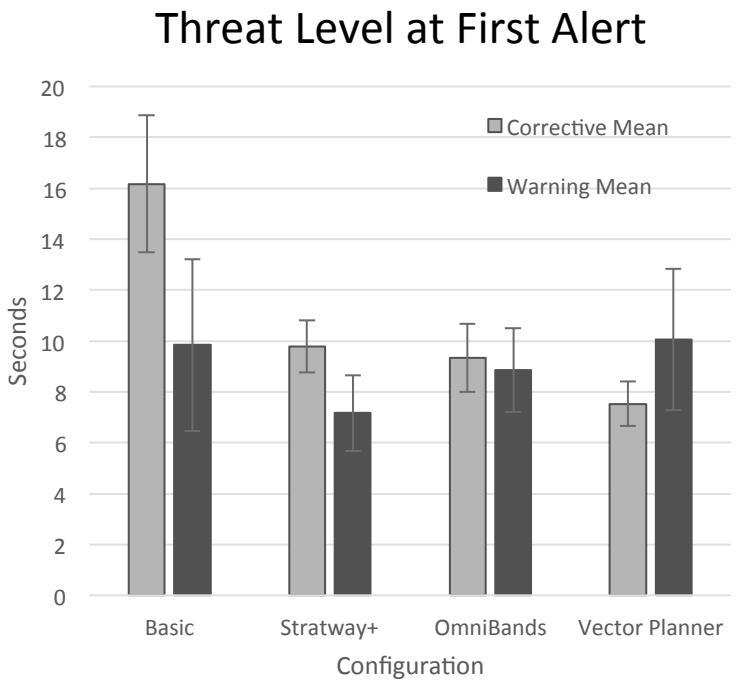


- ~~There was no significant effect of Display on Total Response Time for all SS alerts, p > .05~~
- Pilots took an overall average of **10.7 seconds** to upload their final maneuver after the initiation of an edit
  - Median = 7 seconds

- 50% of pilots completed their final upload within **7 seconds** of the initiation of an edit
- 90% of pilots completed their final upload within **22 seconds** of the initiation of an edit

Total Edit Time

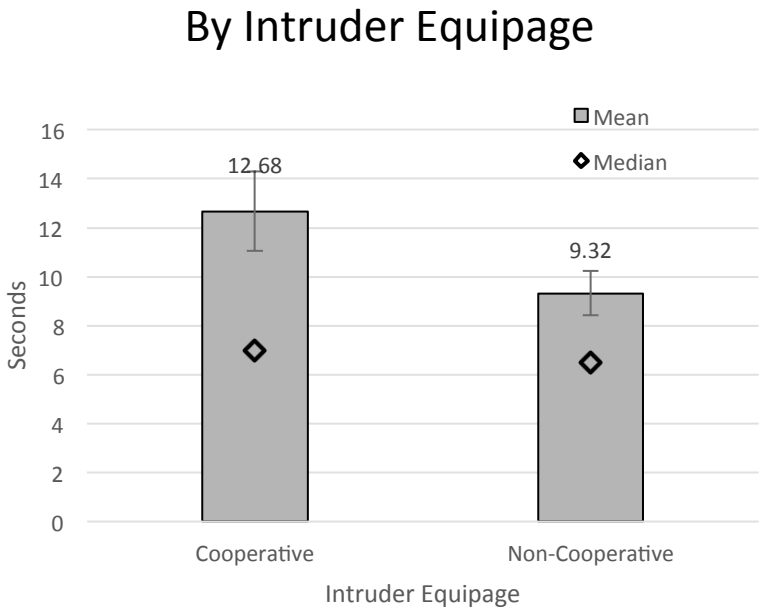


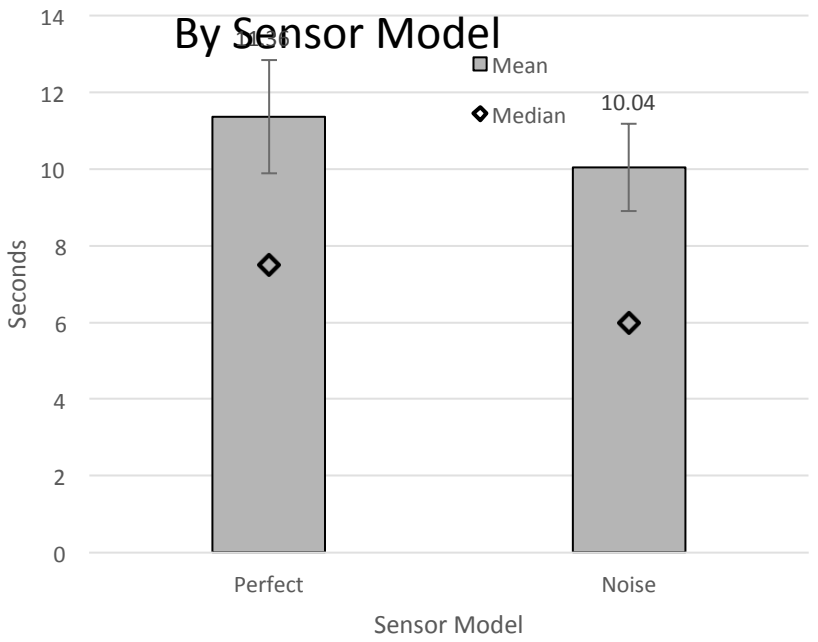


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average made initial edits **3.32 seconds** faster following an SS Warning alert than a Corrective SS alert
  - Median Difference = 1 second faster in response to SS Warning alert

- Unable to test for significant interaction
  - ~~Much larger differences between Corrective Notify times and Warning Notify times for D1 and D4~~

Total Edit Time



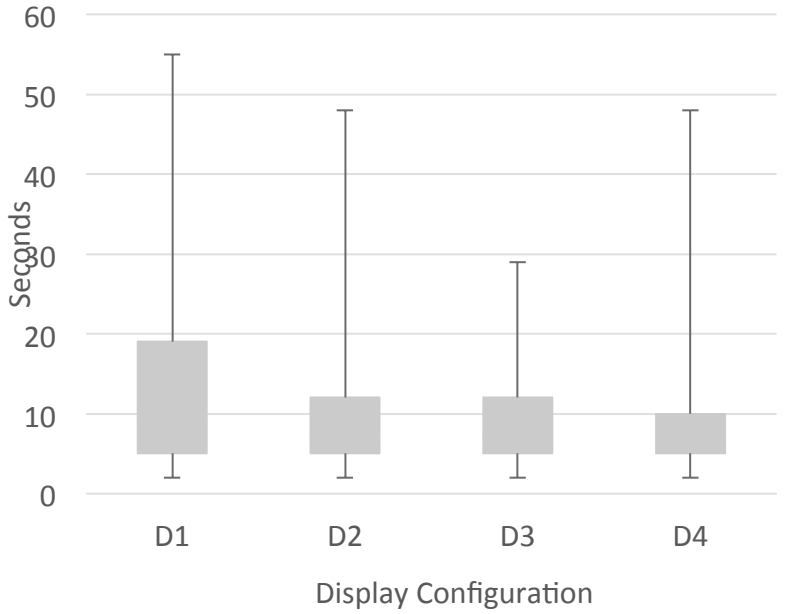


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average made initial edits **0.43 seconds** faster in response to alerts to non - cooperative aircraft
  - Median Difference = 0 seconds faster in response to non-cooperative traffic

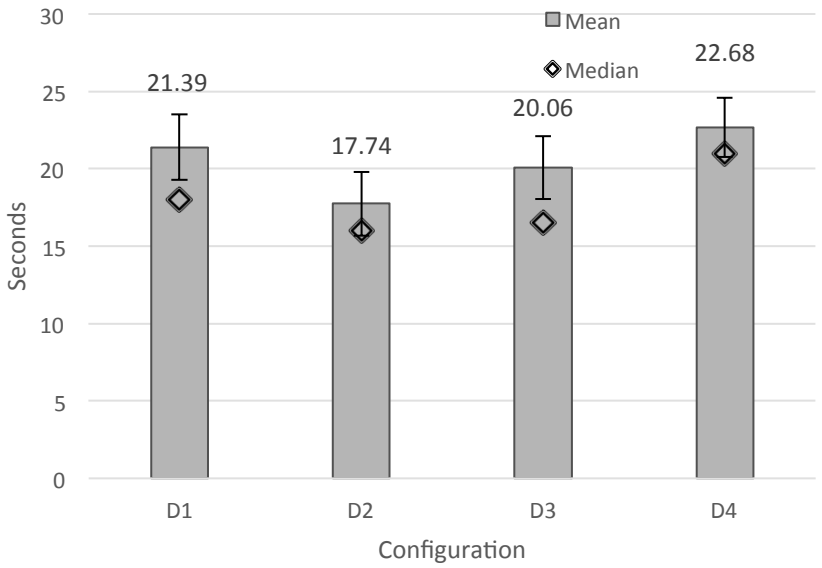
- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average made initial edits **1.10 seconds** faster in the noisy sensor model condition
  - Median Difference = 1 seconds faster in noisy sensor model condition

Total Edit Time

	D1	D2	D3	D4
Min	2	2	2	2
Q1	5	5	5	5
Median	9	7	7	6
Q3	19	12	12	10
Max	55	48	29	48



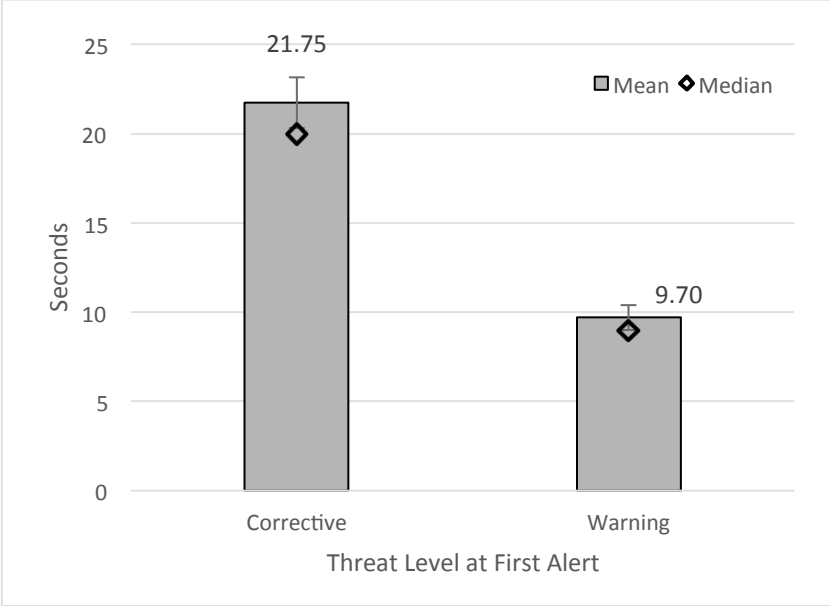
Aircraft RT Time

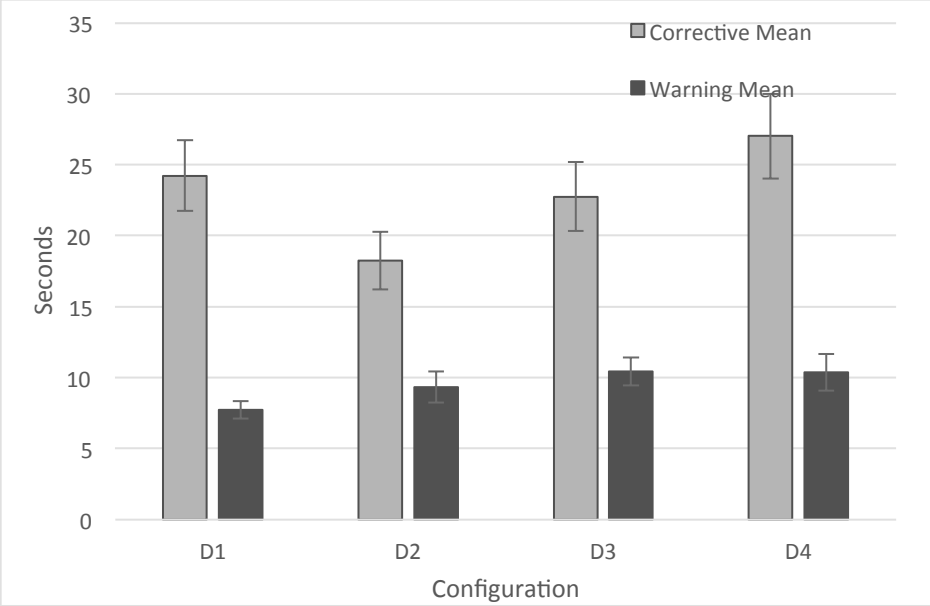


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots took an overall average of **20 seconds** to start a maneuver in response to a Corrective SS or SS Warning alert
  - Median = 18 seconds

- ~~50% of pilots notified ATC within **12 seconds** of the onset of the alert~~
- ~~90% of pilots notified ATC within **32 seconds** of the onset of the alert~~

Aircraft RT Time

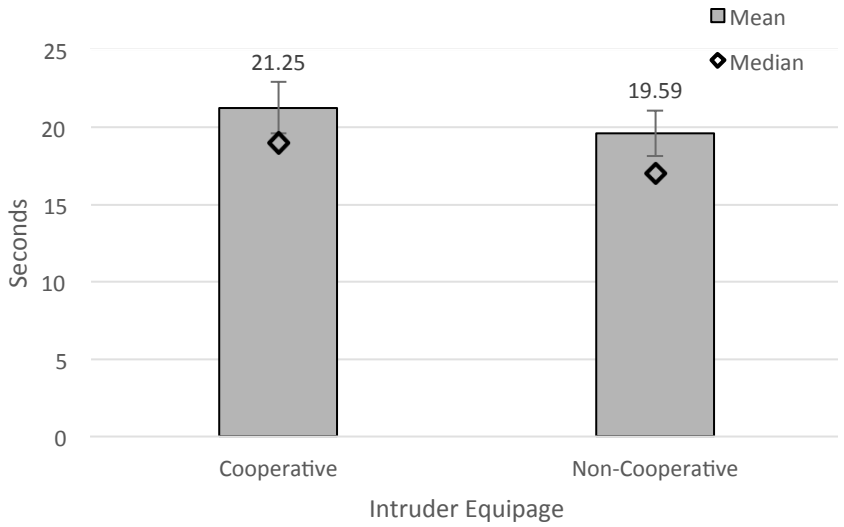




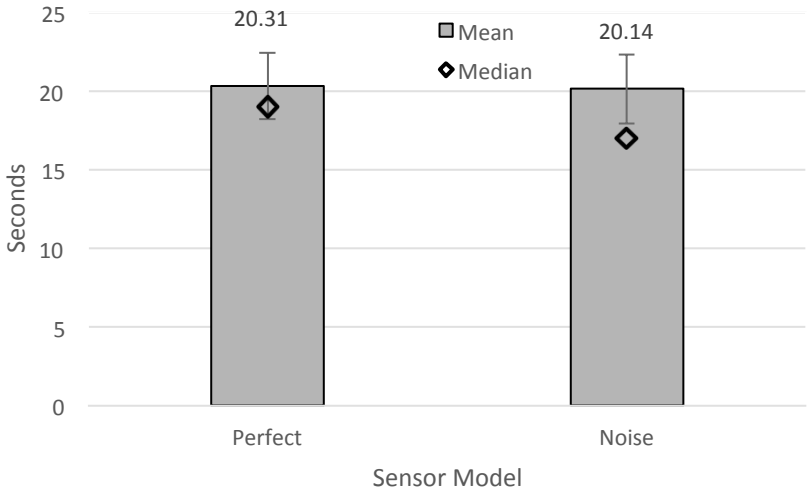
- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average started a maneuver **12.05 seconds** faster following an SS Warning alert than a Corrective SS alert
  - Median Difference = X second faster in starting a maneuver to SS Warning alert
- Unable to test for significant interaction
  - ~~Much larger differences between Corrective Notify times and Warning Notify times for D1 and D4~~

Aircraft RT Time

By Intruder Equipage



By Sensor Model

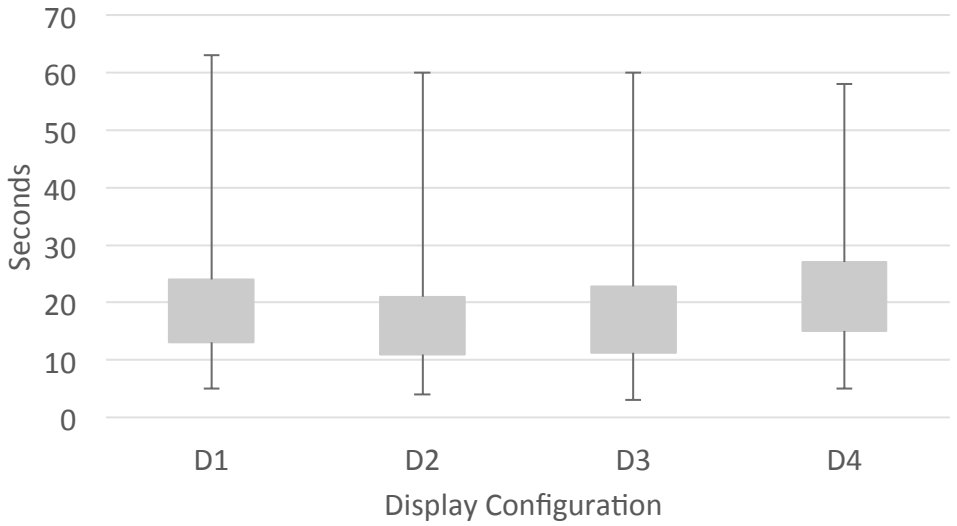


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average started a maneuver **1.66 seconds** faster in response to alerts to non-cooperative aircraft
  - Median Difference = 2 seconds faster in starting a maneuver to non-cooperative traffic

- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average completed maneuvers **0.17 seconds** faster in the noisy sensor model condition
  - Median Difference = 2 seconds faster in noisy sensor model condition

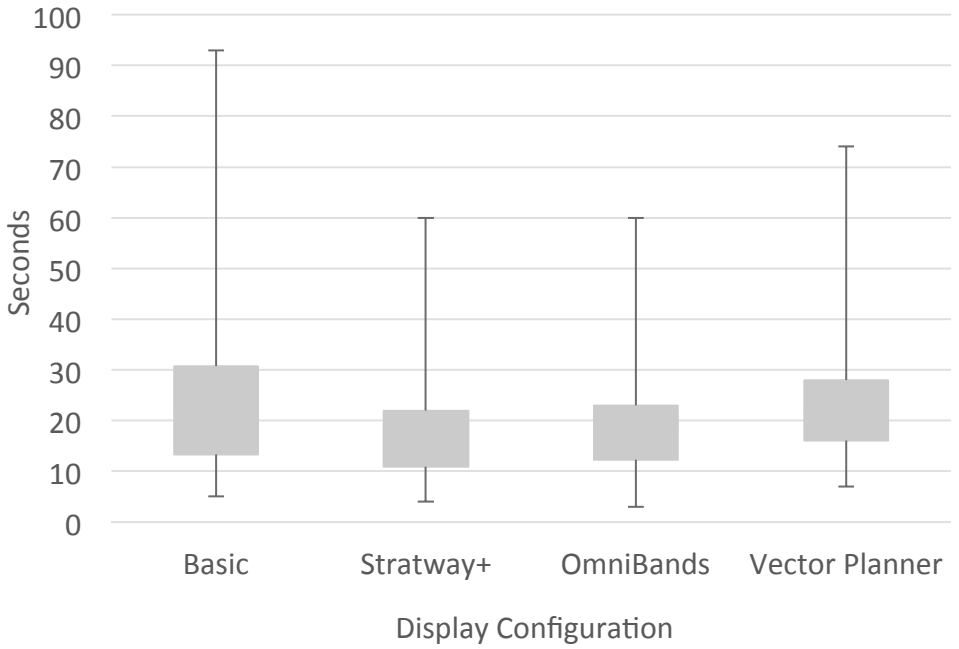
Aircraft RT Time

	D1	D2	D3	D4
Min	5	4	3	5
Q1	13	11	11.25	15
Median	18	16	16.5	21
Q3	24	21	22.75	27
Max	63	60	60	58

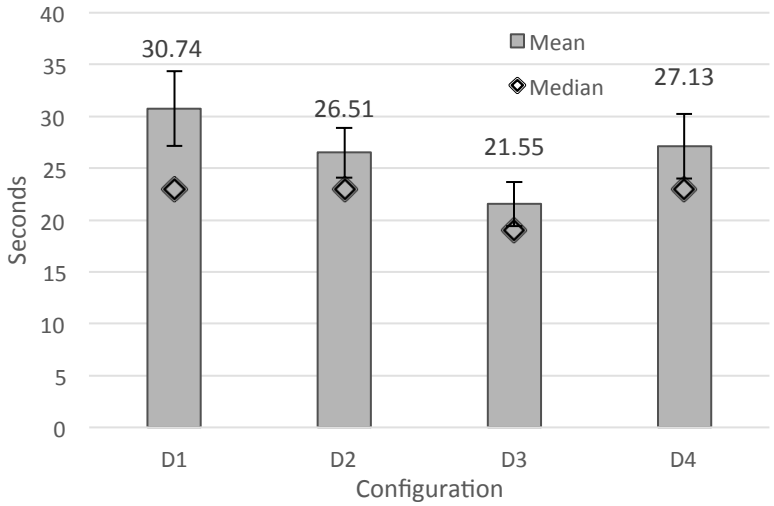


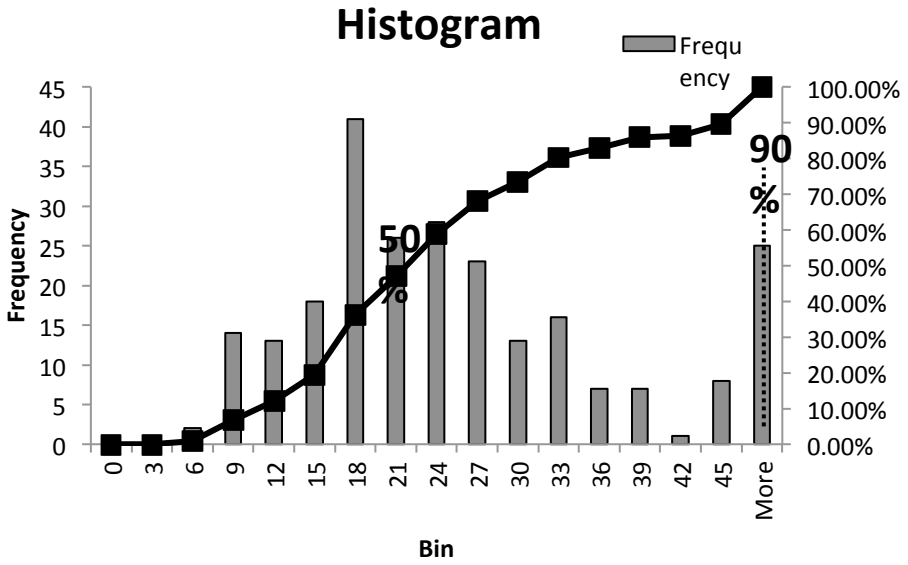
Total Response Time

	D1	D2	D3	D4
Min	5	4	3	7
Q1	13.25	11	12.25	16
Median	22	17	18	21
Q3	30.75	22	23	28
Max	93	60	60	74



Alert Duration Time

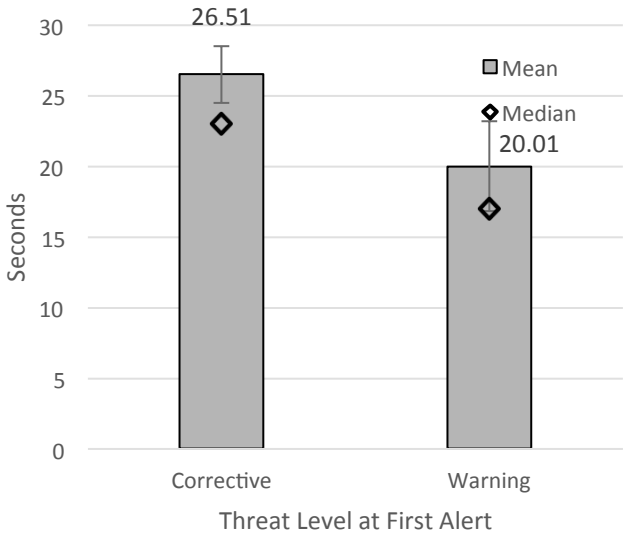


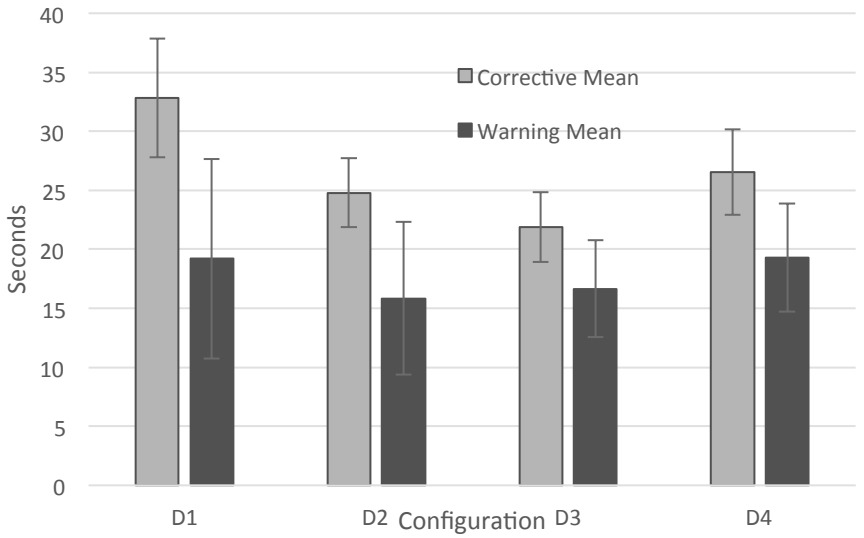


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots took an overall average of **26.48 seconds** to eliminate a Corrective SS or SS Warning alert
  - Median = 22 seconds

- 50% of pilots cleared an alert within **21 seconds** of its onset
- 90% of pilots cleared an alert within **45 seconds** of its onset

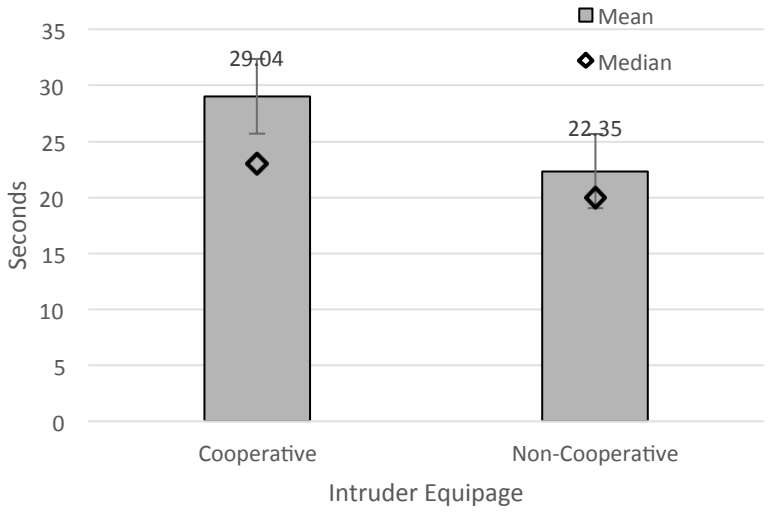
Alert Duration Time

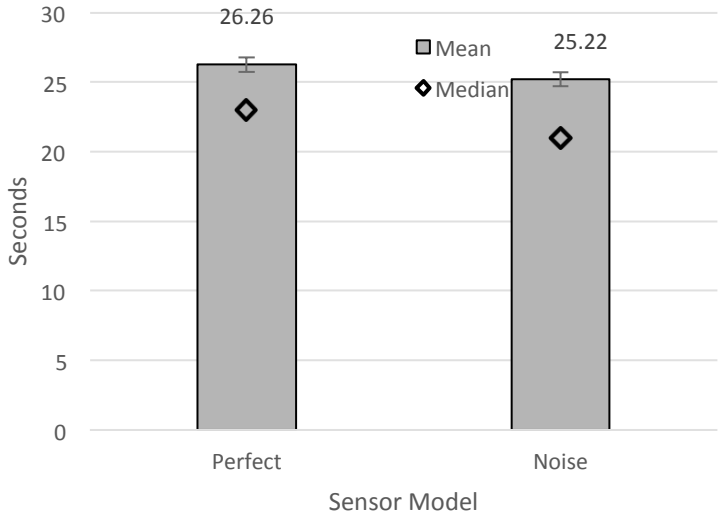




- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average cleared an alert **6.50 seconds** faster following an SS Warning alert than a Corrective SS alert
  - Median Difference = 6 second faster in response to an SS Warning alert
- Unable to test for significant interaction
  - Nothing approaching an interaction

Alert Duration Time



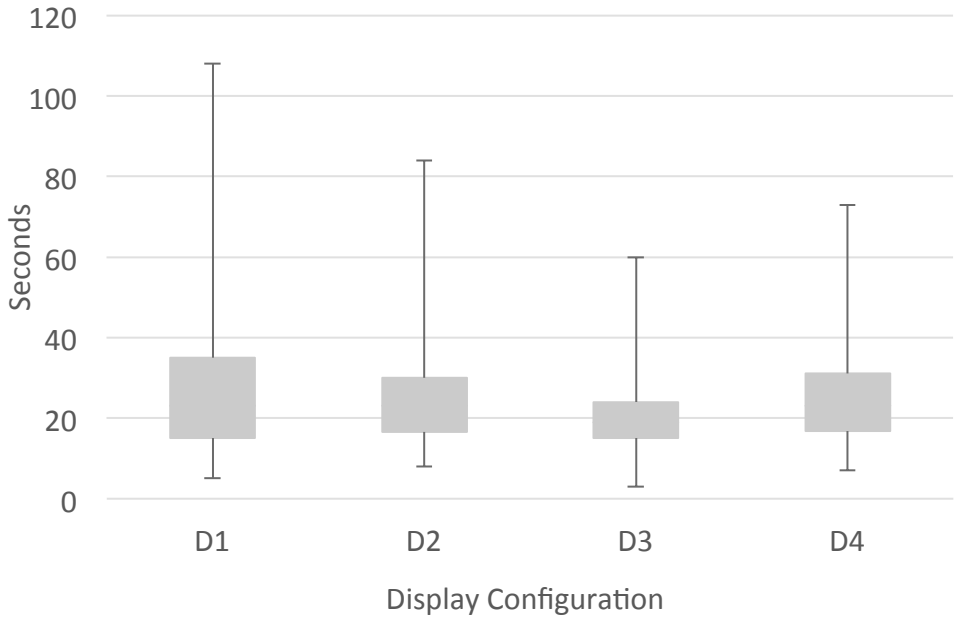


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average cleared an alert **6.69 seconds** faster in response to alerts to non-cooperative aircraft
  - Median Difference = 3 seconds faster in response to non-cooperative traffic

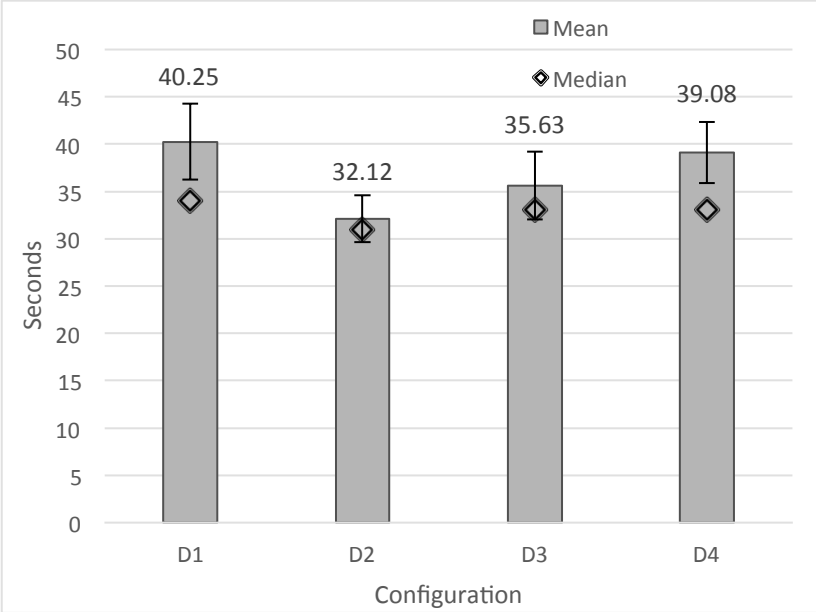
- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average cleared an alert **1.04 seconds** faster in the noisy sensor model condition
  - Median Difference = 2 seconds faster in the noisy sensor model condition

Alert Duration Time

	D1	D2	D3	D4
Min	5	8	3	7
Q1	15	16.5	15	16.75
Median	23	23	19	23
Q3	35	30	24	31
Max	108	84	60	73



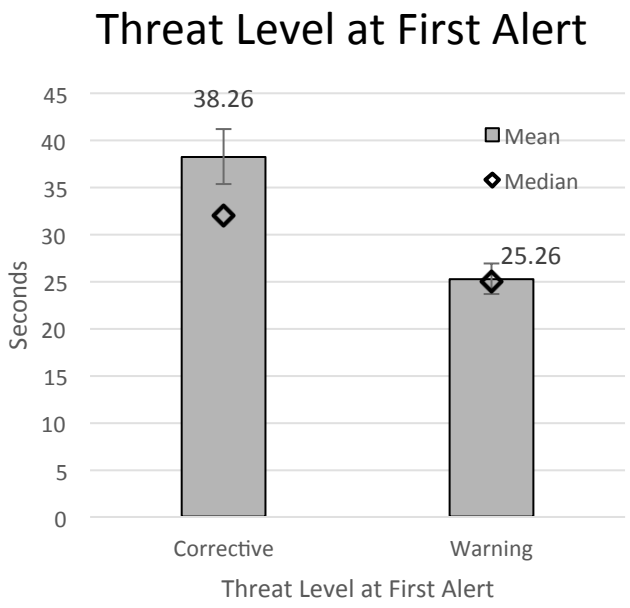
Compliance Time

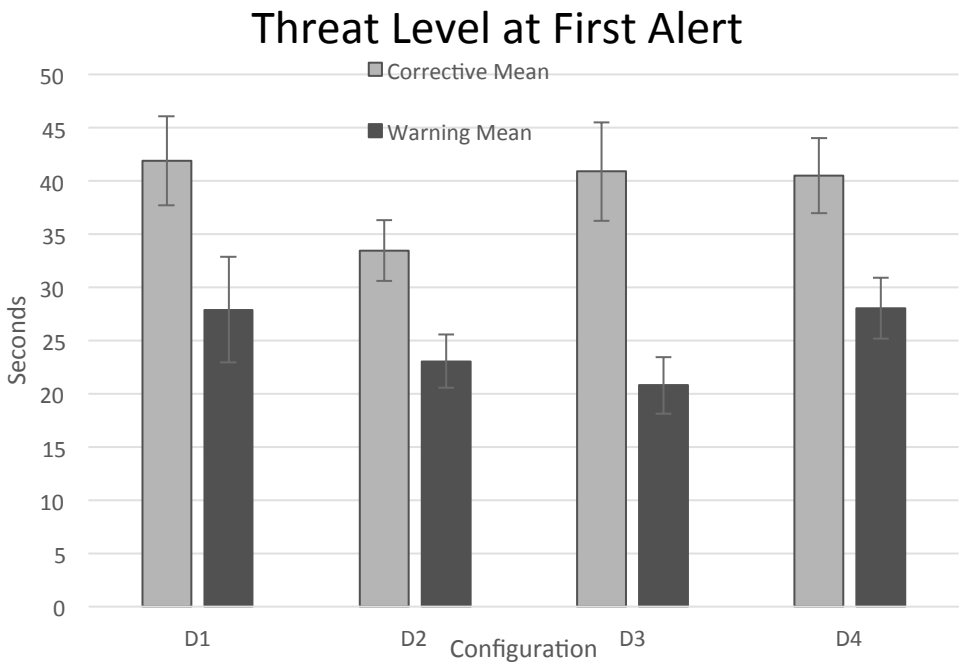


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots took an overall average of **36.77 seconds** to complete a maneuver following a Corrective SS or SS Warning alert
  - Median = 33 seconds

- ~~50% of pilots notified ATC within **12 seconds** of the onset of the alert~~
- ~~90% of pilots notified ATC within **32 seconds** of the onset of the alert~~

Compliance Time

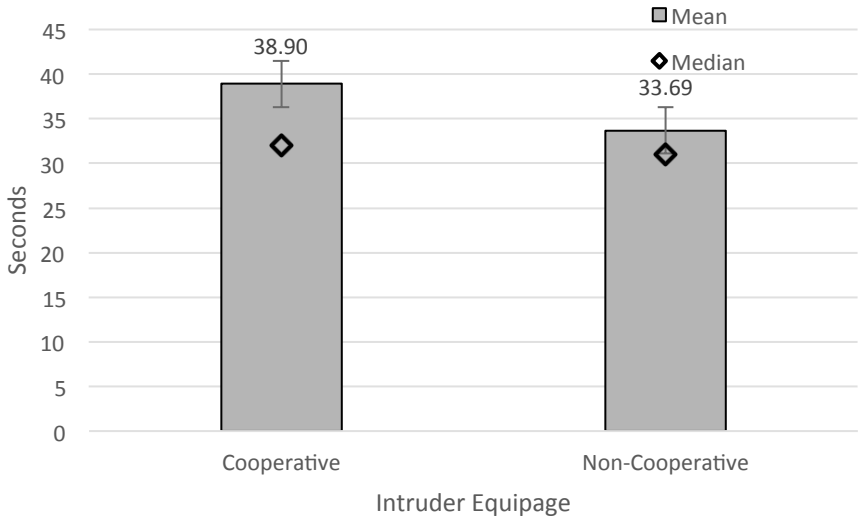




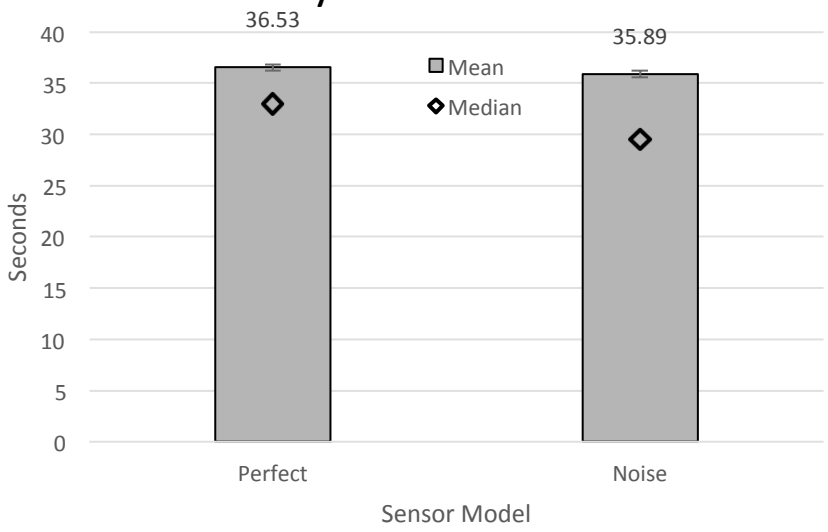
- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average completed a maneuver **13.00 seconds** faster following an SS Warning alert than a Corrective SS alert
  - Median Difference = 7 seconds faster in completion of maneuver to SS Warning alert
- Unable to test for significant interaction

Compliance Time

By Intruder Equipage



By Sensor Model

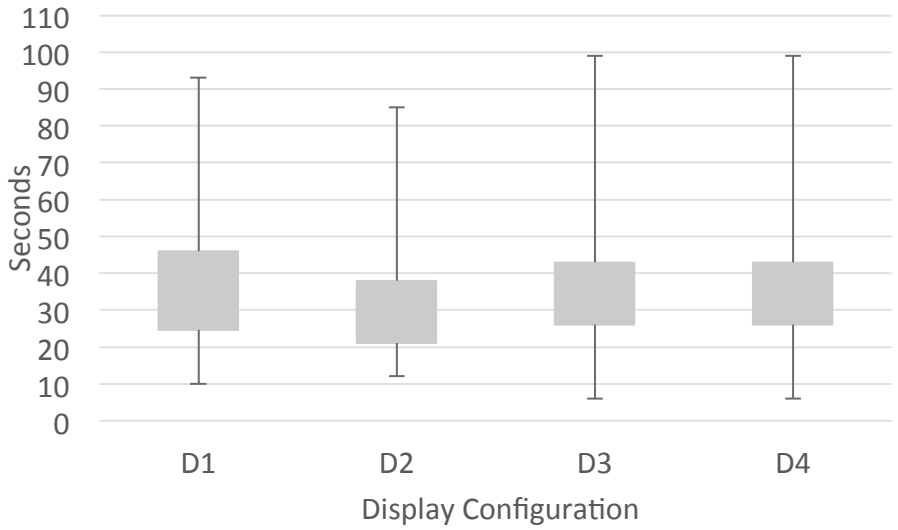


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average completed maneuvers **5.21 seconds** faster in response to alerts to non-cooperative aircraft
  - Median Difference = 1 seconds faster in maneuver completion to non-cooperative traffic

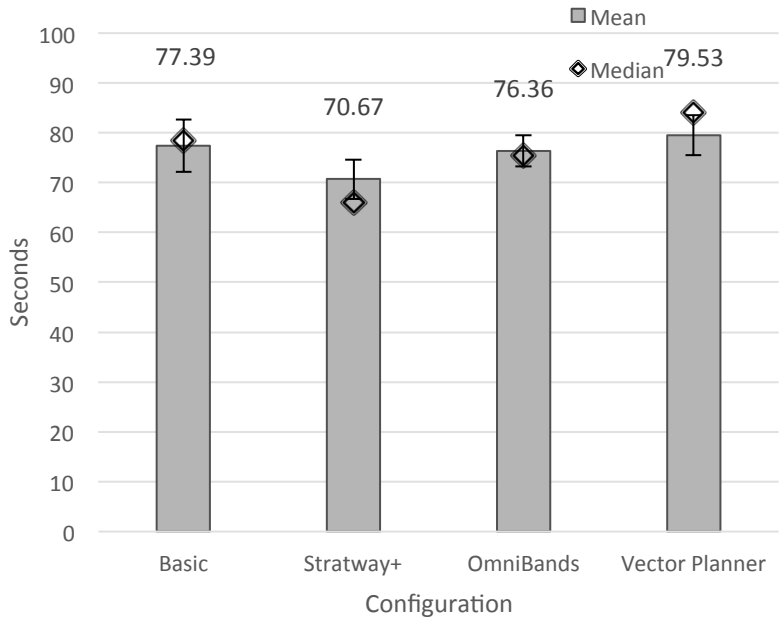
- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average completed maneuvers **0.64 seconds** faster in the noisy sensor model condition
  - Median Difference = 3.5 seconds faster in noisy sensor model condition

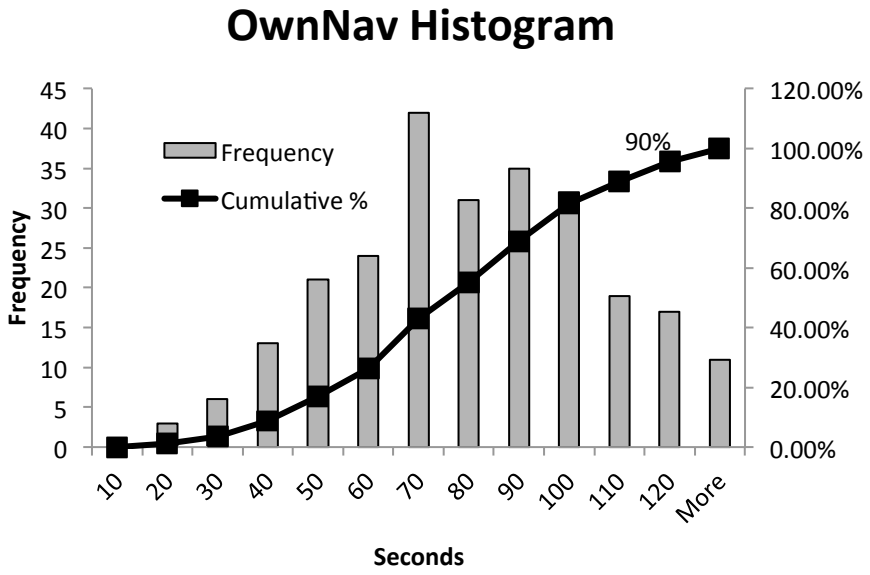
Compliance Time

	D1	D2	D3	D4
Min	10	12	6	6
Q1	24.75	21	26	26
Median	34	31	33	33
Q3	46	38	43	43
Max	93	85	99	99



Resume Own Navigation

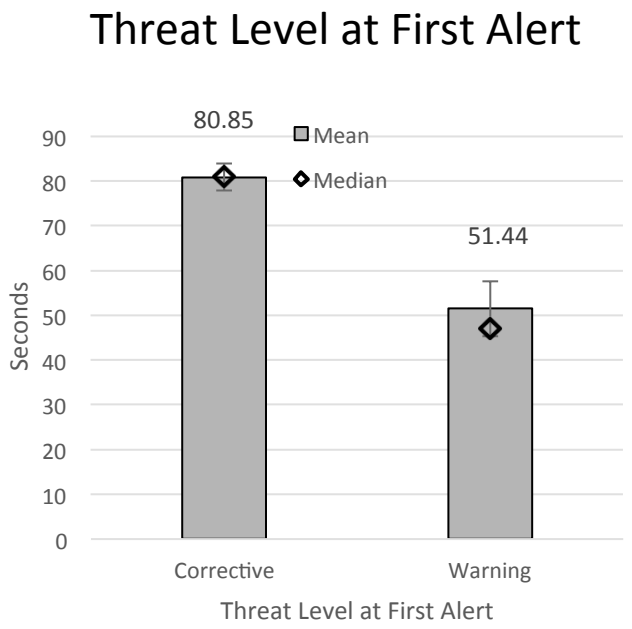


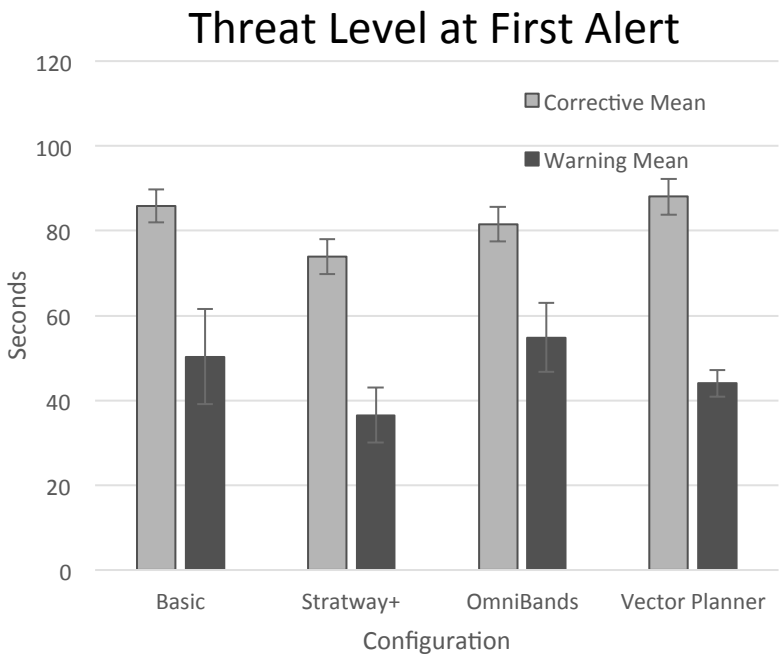


- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots took an overall average of **36.77 seconds** to complete a maneuver following a Corrective SS or SS Warning alert
  - Median = 33 seconds

- ~~50% of pilots notified ATC within **12 seconds** of the onset of the alert~~
- ~~90% of pilots notified ATC within **32 seconds** of the onset of the alert~~

Resume Own Navigation

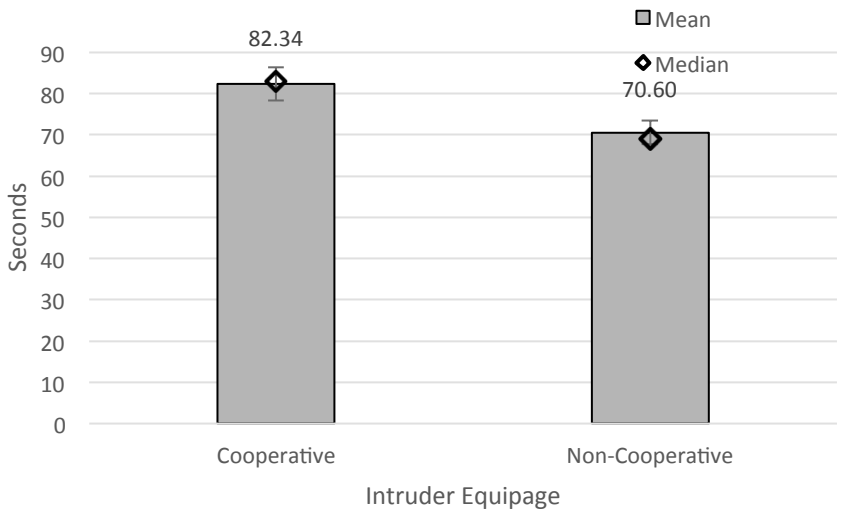




- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average completed a maneuver **13.00 seconds** faster following an SS Warning alert than a Corrective SS alert
  - Median Difference = 7 seconds faster in completion of maneuver to SS Warning alert
- Unable to test for significant interaction

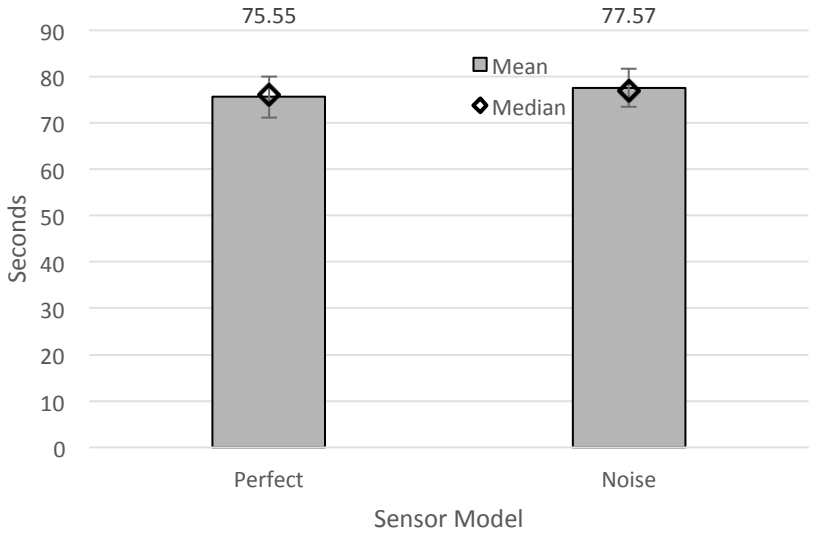
Resume Own Navigation

By Intruder Equipage



- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average completed maneuvers **5.21 seconds** faster in response to alerts to non-cooperative aircraft
  - Median Difference = 1 seconds faster in maneuver completion to non-cooperative traffic

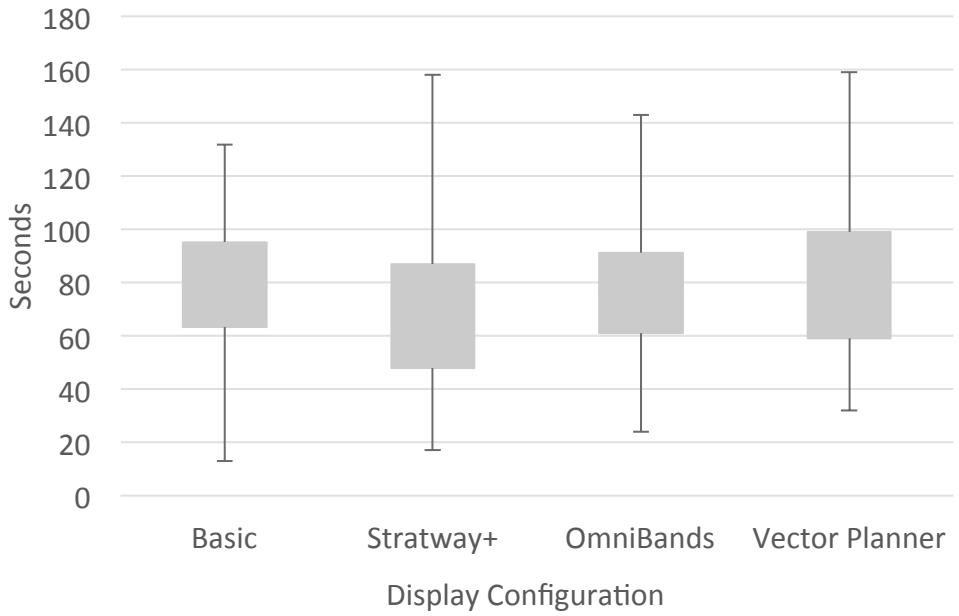
By Sensor Model



- ~~There was no significant effect of Display on Initial Response Time for all SS alerts, p > .05~~
- Pilots on average completed maneuvers **0.64 seconds** faster in the noisy sensor model condition
  - Median Difference = 3.5 seconds faster in noisy sensor model condition

Resume Own Navigation

	D1	D2	D3	D4
Min	13	17	24	32
Q1	63.5	48	61	59
Median	78.5	66	75.5	84
Q3	95.25	87	91.25	99
Max	132	158	143	159



NASA-TLX Summary

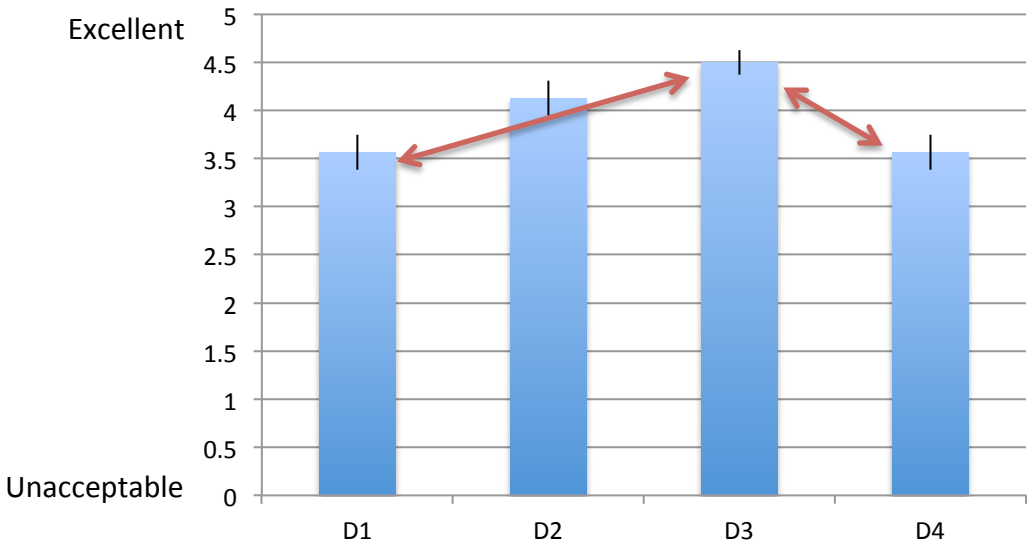
- Omni Bands (D3) resulted in significantly lower workload ratings than the Vector Planner (D4) for *5 of the 6 scales*:
  - Mental, Temporal, Effort, Frustration, & Performance Degradation
    - Only Physical Demands failed to result in a significant difference
- Frustration was the only scale that resulted in more than one significant difference
  - Stratway Bands (D2) were also significantly less impactful than the Vector Planner (D4)
  - Omni Bands (D3) were also significantly less impactful than the Information Only condition (D1)

POST-TRIAL QUESTIONNAIRE

BY DISPLAY CONFIGURATION

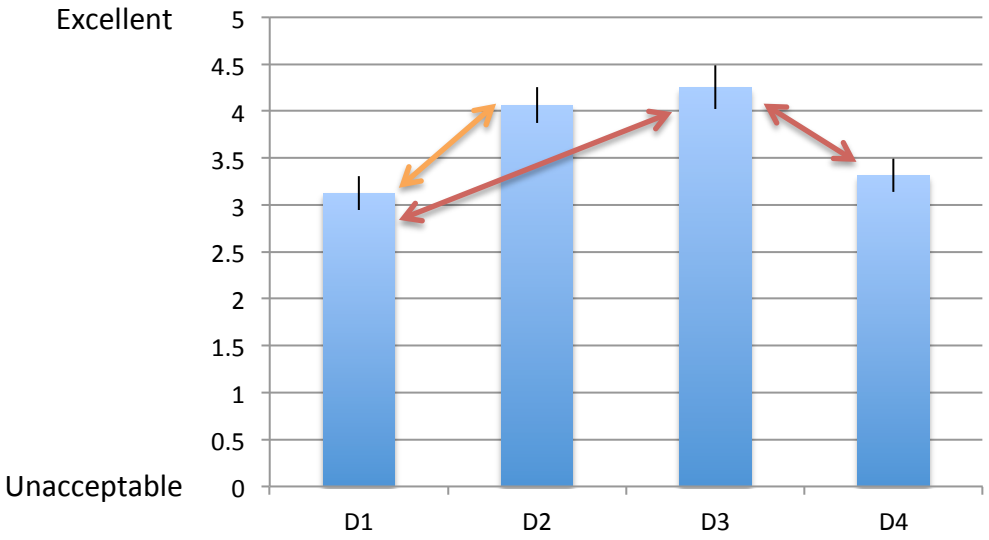
Post Trial

- Question 1
  - Rate your ability to maintain separation from other aircraft ($p < 0.001$)
    - Difference between D1 and D3 ($p < 0.001$)
    - Difference between D3 and D4 ($p = 0.006$)



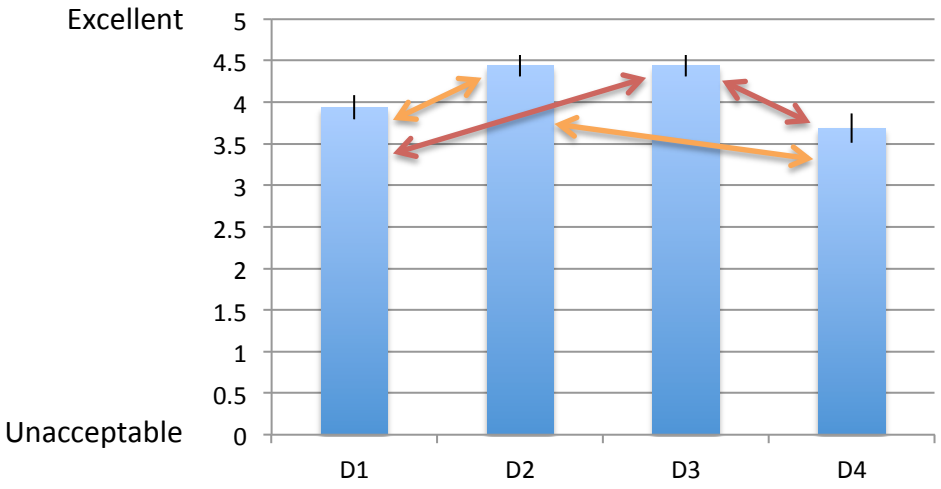
Post Trial

- Question 2
  - Rate your ability to minimize deviations from the planned path ($p < 0.001$)
    - Difference between D1 and D2 ($p = 0.003$)
    - Difference between D1 and D3 ($p = 0.003$)
    - Difference between D3 and D4 ($p = 0.003$)



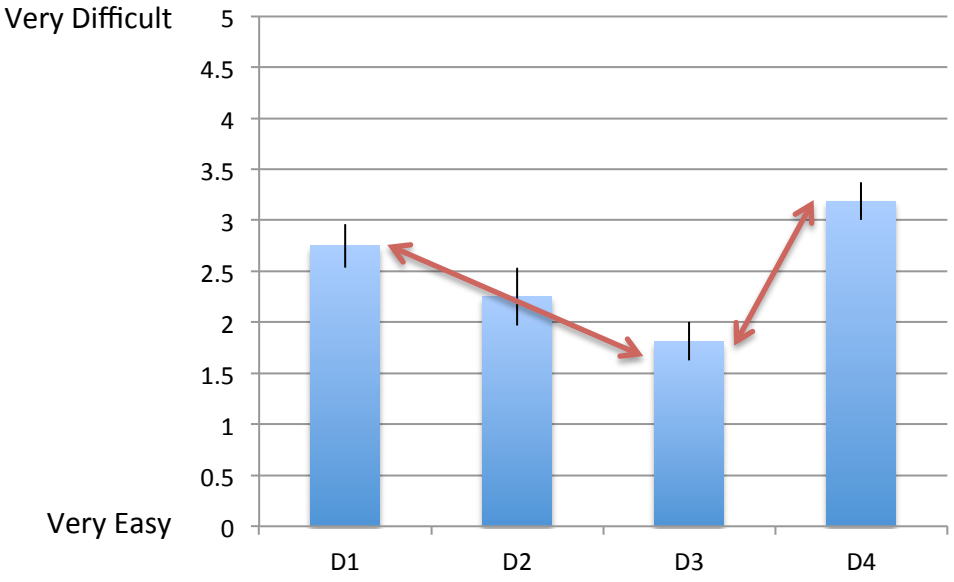
Post Trial

- Question 3
  - Rate your ability to handle all pilot tasks ($p = 0.001$)
    - Difference between D1 and D2 ($p = 0.039$)
    - Difference between D1 and D3 ($p = 0.039$)
    - Difference between D2 and D4 ($p = 0.034$)
    - Difference between D3 and D4 ($p = 0.054$)



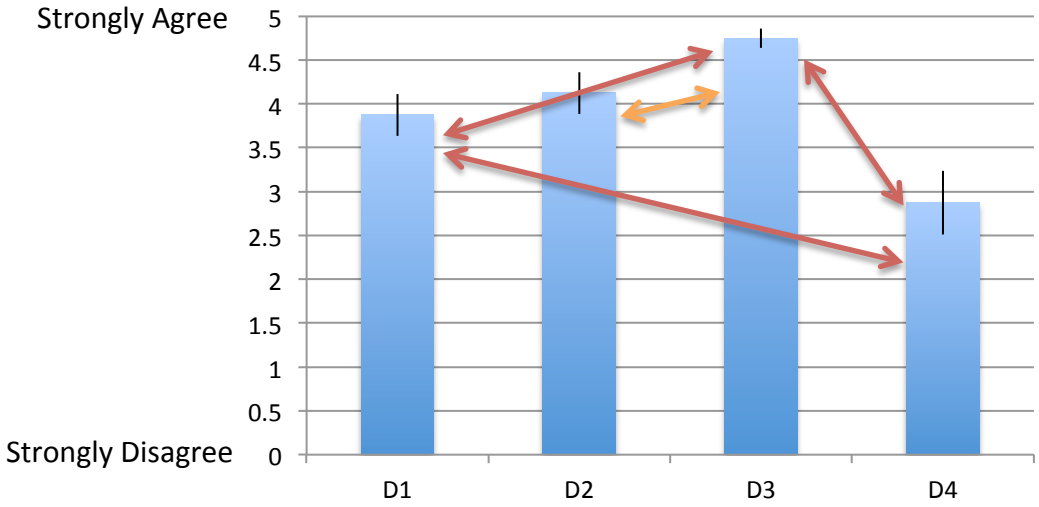
Post Trial

- Question 4
  - Rate the complexity of the encounters in this trial ($p < 0.001$)
    - Difference between D1 and D3 ($p = 0.011$)
    - Difference between D3 and D4 ($p < 0.001$)



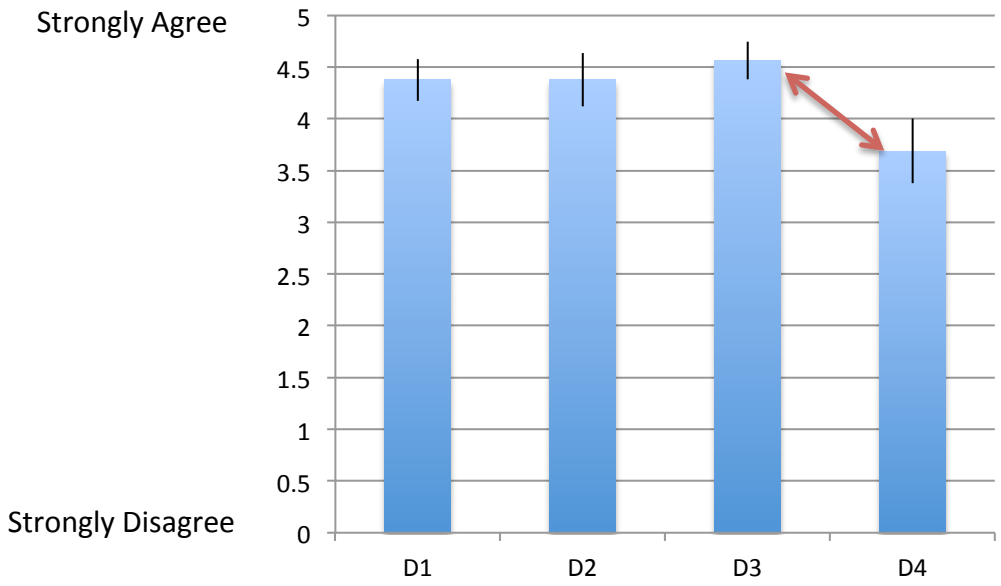
Post Trial

- Question 6
  - This display was easy to use (p = 0.001)
    - Difference between D1 and D3 (p = 0.035)
    - Difference between D1 and D4 (p = 0.050)
    - Difference between D2 and D3 (p = 0.020)
    - Difference between D3 and D4 (p = 0.001)



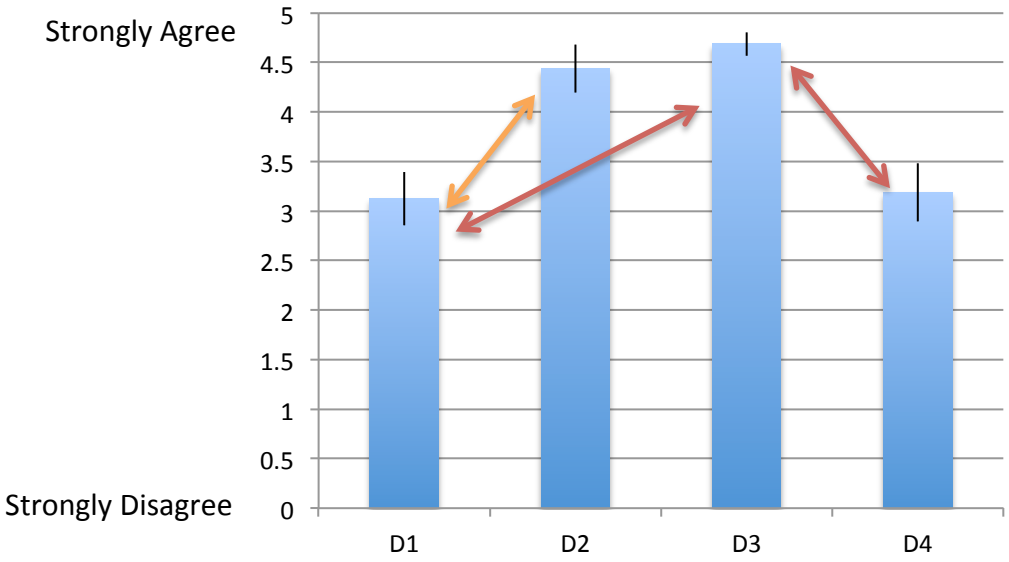
Post Trial

- Question 7
  - This display was easy to understand (Marginal, p = 0.069)
    - Difference between D3 and D4



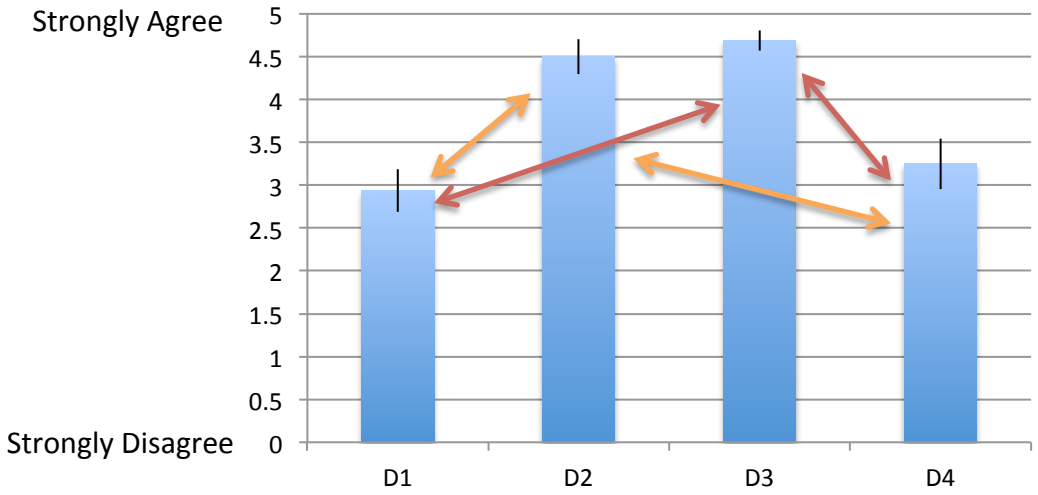
Post Trial

- Question 8
  - This display provided the necessary information to predict a potential loss of separation ($p < 0.001$)
    - Difference between D1 and D2 ($p = 0.009$)
    - Difference between D1 and D3 ($p < 0.001$)
    - Difference between D3 and D4 ($p = 0.002$)



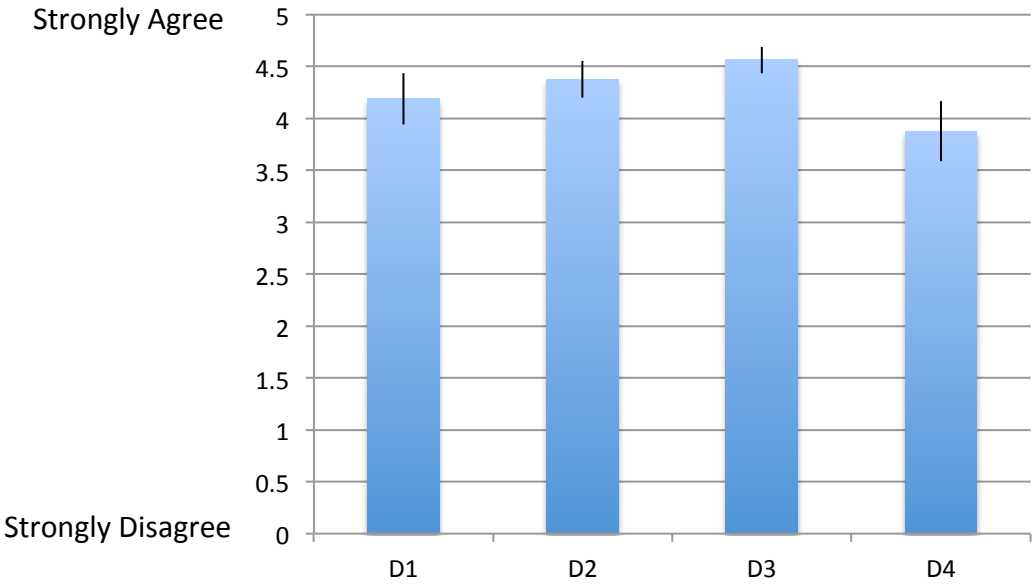
Post Trial

- Question 9
  - This display provided the necessary information to perform a maneuver for separation ($p < 0.001$)
    - Difference between D1 and D2 ($p = 0.005$)
    - Difference between D1 and D3 ($p < 0.001$)
    - Difference between D2 and D4 ($p = 0.037$)
    - Difference between D3 and D4 ($p = 0.003$)



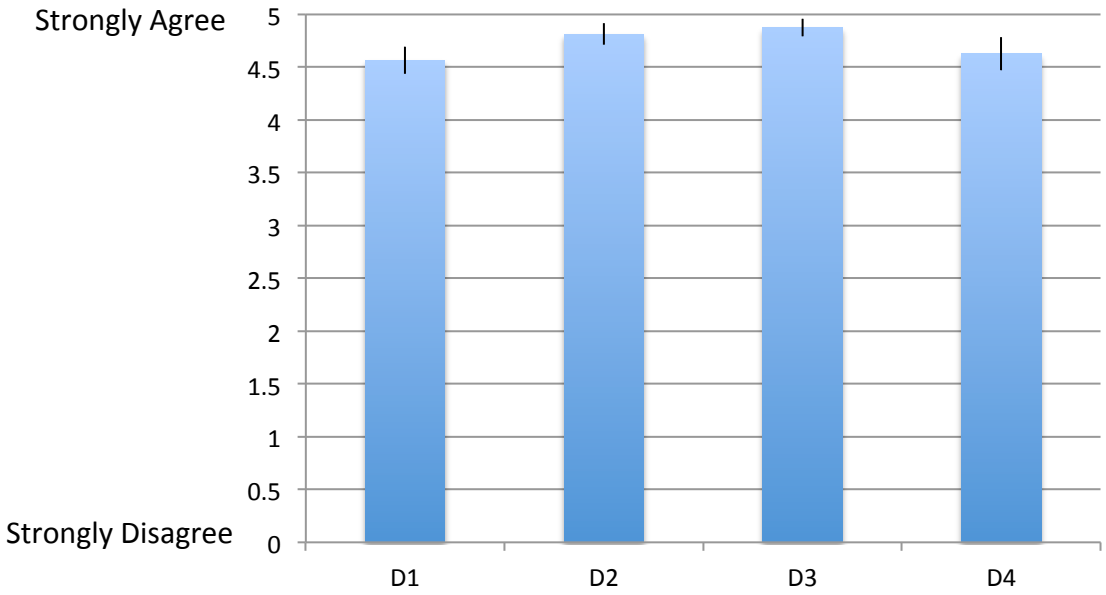
Post Trial

- Question 10
  - I trusted the accuracy of the information provided by the display (p = *NS*)



Post Trial

- Question 11
  - I felt I had enough training with this display to be able to operate it safely during this trial (*p* = *NS*)



POST-SIM QUESTIONNAIRE

Visual Alert Levels

	Preventive Self Separation Alert	*Corrective Self Separation Alert*	*Self Separation Warning Alert*
1. The visual display of this alert (i.e., icon color, shape, etc.) was easy to understand	M = 4.44 SE = 0.16	M = 4.50 SE = 0.13	M = 5.0 SE = 0.0
2. Based on this alert, I would likely contact ATC and *then* maneuver	M = 2.50 SE = 0.38	M = 3.81 SE = 0.31	M = 1.38 SE = 0.26
3. Based on this alert, I would likely maneuver *prior* to contacting ATC	M = 1.56 SE = 0.20	M = 2.63 SE = 0.27	M = 5.00 SE = 0.0

Scale	
1	Strongly Disagree
2	Somewhat Disagree
3	Neither Agree nor Disagree
4	Somewhat Agree
5	Strongly Agree

Question 4

- Asked pilots if they understood which of the 3 alerts would lead to a LoWC if ownship and intruder trajectories remained unchanged
  - 14/16 pilots correctly reported that Corrective SS and SS Warning alerts were predicted to lead to LoWC & Preventive SS were not
  - 1 pilot incorrectly reported that a Preventive SS was predicted to lead to LoWC
  - 1 pilot incorrectly reported that Corrective SS would not lead to LoWC
- In debrief, all 16 pilots demonstrated that they correctly understood alerting structure

Auditory Alert Levels

	"Traffic, Monitor"	*"Traffic, Separate"*	*"Traffic, Maneuver Now"*
5. This auditory alert was clearly distinguishable from the other auditory alerts	M = 4.13 SE = 0.24	M = 4.25 SE = 0.21	M = 4.68 SE = 0.18
6. This auditory alert was useful for maintaining separation	M = 3.75 SE = 0.23	M = 4.31 SE = 0.20	M = 4.68 SE = 0.15

Scale	
1	Strongly Disagree
2	Somewhat Disagree
3	Neither Agree nor Disagree
4	Somewhat Agree
5	Strongly Agree

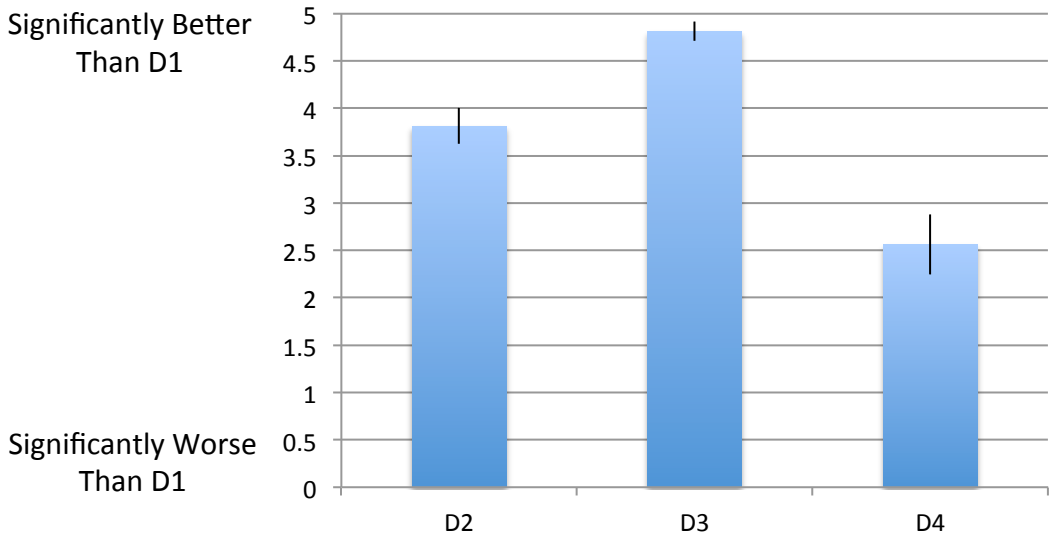
Alert Timing

	Preventive Self Separation Alert	*Corrective Self Separation Alert*	*Self Separation Warning Alert*
7. The onset of the alert was: _____	M = 3.00 SE = 0.0	M = 3.06 SE = 0.06	M = 3.13 SE = 0.13

Scale	
1	Too Early
2	Somewhat Early
3	Appropriate
4	Somewhat Late
5	Too Late

Questions 8-10

- Compared to the information only display, how did the other three displays affect your ability to maintain separations?



Question 11

- Rank the following display configurations in order of their effects on your ability to maintain separation
  - 1st = Best Supported; 4th = Least Supported

Rank	D1	D2	D3	D4
1st	0/16	2/16	**14/16**	0/16
2nd	1/16	**10/16**	1/16	4/16
3rd	**8/16**	3/16	1/16	4/16
4th	**7/16**	1/16	0/16	**8/16**
Avg.	*3.38*	*2.19*	*1.19*	*3.25*

Additional Questions

- *Question 12:*
  - Did you notice any noise in the position data for aircraft within range?
    - 4/8 pilots reported 'Yes' (i.e., ½ of the pilots that received the noisy condition)
- *Question 13:*
  - Did you want to know which sensor was tracking the target
    - 7/16 of the pilots reported 'Yes'
- *Question 14:*
  - Do you think non-cooperative traffic need different visual or auditory alerting than cooperative traffic?
    - 5/16 of the pilots reported 'Yes'

Additional Questions

- *Question 15:*
  - Was the surveillance volume/range sufficient to maintain separation from:
    - Cooperative traffic: All 16 pilots reported 'Yes'
    - Non-Cooperative traffic: All 16 pilots reported 'Yes'
- *Question 16:*
  - The flight ID was useful with non-cooperative traffic?
    - $M = 4.375$ (Slightly/Strongly Agree)
- *Question 17:*
  - Did you want to see the flight ID with non-cooperative traffic
    - 11/16 pilots reported 'Yes'

Question 18

- Did any of the following factors influence whether you decided to make a **<u>horizontal</u>** maneuver? *Please circle **all** relevant factors*.
  - Mission Profile 11/16
  - Whether or not ownship was in level flight 8/16
  - Encounter Geometry 12/16
  - Uncertainty 7/16
  - Other* _____ 7/16
  - None 1/16

*"Other" answers from pilots:

- Visual cue of non-overlapping AC, feel safer
- Knowing where the other AC was leveling off
- Speed of AC/Closure Rate
- ATC preference for maintaining altitude
- Amount of anticipated deviation

Question 19

- Did any of the following factors influence whether you decided to make a **vertical** maneuver? *Please circle **all** relevant factors*.
  - Mission Profile 8/16
  - Whether or not ownship was in level flight 7/16
  - Encounter Geometry 10/16
  - Uncertainty 4/16
  - Other _____ 7/17
  - None 2/16

*"Other" answers from pilots:
  - Whether the intruder was climbing or descending
  - Knowing where the other AC was leveling off
  - Speed of AC/Closure Rate
  - Follow on manipulation of lost/link emergency
  - Time to return from deviation
  - Alt changes are different in RPAs too much to change

END-OF-SIM DEBRIEF

Debrief

- Question 1
  - Do you view proximal alerts as a "pre alert" or as an indication of proximity?
    - Proximity 5/16
    - Pre-alert 7/16
    - Both 2/16
    - General awareness 1/16
    - Didn’t attend to or notice them 1/16

Debrief

- Question 2
  - Did you clearly understand the meaning of the 4 different alerts?
    - 16 clearly understood
    - 1 pilot stated corrective should be red since it expects you to take action

Debrief

- Question 3
  - Did you find the meaning/intent of the 4 different alerts distinct from one another
    - 16 pilots said yes
      - All pilots liked the alerting system and thought it was clear and logically progressive
    - However, 5/16 pilots reported that the least meaningful/useful difference was between the corrective and warning alerts – e.g., “if I have to maneuver, it should be red/a warning”

Debrief

- Question 4
  - Did you find the auditory alerts easy to understand? If no, what could be improved upon
    - 15 pilots said yes
      - 4 pilots said they treated audio more as a cue to check out visual
    - 1 pilot said the difference between ‘separate’ and ‘maneuver now’ did not seem clear

Debrief

- Question 5
  - Did you feel that the auditory alerts complimented the associated meaning of the alerts
    - 14/16 pilots thought they complimented the associated meaning
    - 1 pilot found ‘separate’ and ‘monitor’ ambiguous
    - 1 pilot said he liked “maneuver now” the most

- Question 6
  - Did you use any information not provided in the TSD to inform your eventual maneuver?
    - 6/16 pilots looked at Intruder (encounter) geometry
    - 6/16 pilots looked at whether the intruders were climbing/descending around their climbs and descents
    - 2/16 pilots said previous experience
    - 2/16 pilots said minimizing course deviation

- Question 7
  - Did the separation maneuver recommendations usually correspond to what you preferred to do?
    - 5/16 said they were similar maneuvers – i.e., the guidance was recommending maneuvers that made sense to them
    - 6/16 pilots didn't like the trial planner (having to activate, etc.)
    - 3/16 didn't like the Stratway bands because didn't tell which alert would occur
    - 1 pilot didn't like how the algorithms were only trying to minimize deviation size – would prefer to maneuver larger to eliminate the conflict more quickly
    - 1 pilot didn't like the Omni bands going all red

Debrief

- Question 8
  - "Did you find any of the alerts unnecessary?"
    - 13/15 no, all necessary or all served a purpose
    - 1/15 said does not absolutely need the corrective - don't always need to accommodate ATC, can survive just on the warning/maneuver now
    - 1/15 said proximal and preventive were very similar – pay attention but no maneuver needed

Debrief

- Question 9
  - "Was there any additional information you would want to see?"
    - 6/15 said nothing else needed (all there)
    - 4/15 said vertical trend arrow in data tag
    - 3/15 said dead reckoning line
    - 1 said steering window dockable at all times
    - 1 said what to do like a TA/RA

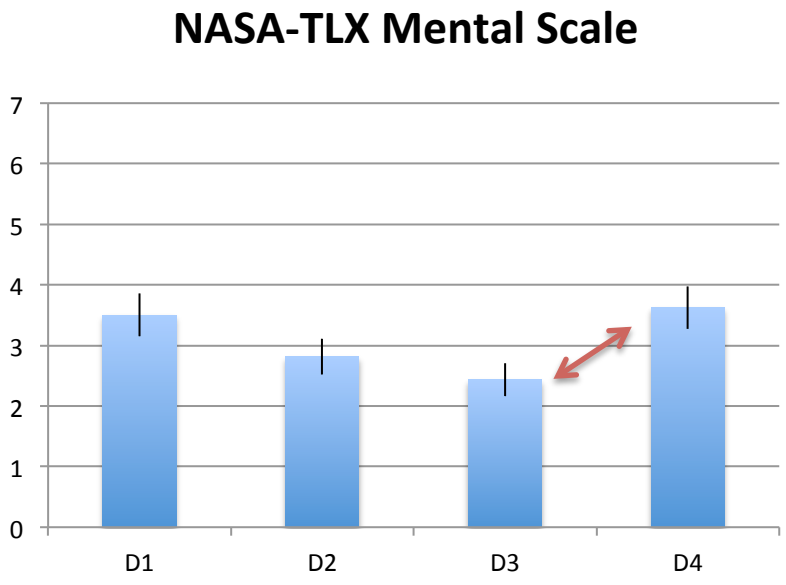
Debrief

- Question 10
  - "What are the minimum horizontal and vertical distances you would comfortably pass by an intruder"?
    - 10/16 - 500ft .75nm
    - 1/16 - 1000ft 1nm
    - 2/16 - 1000ft .75nm
    - 3/16 - Depends on the Aircraft

BACK-UP SLIDES

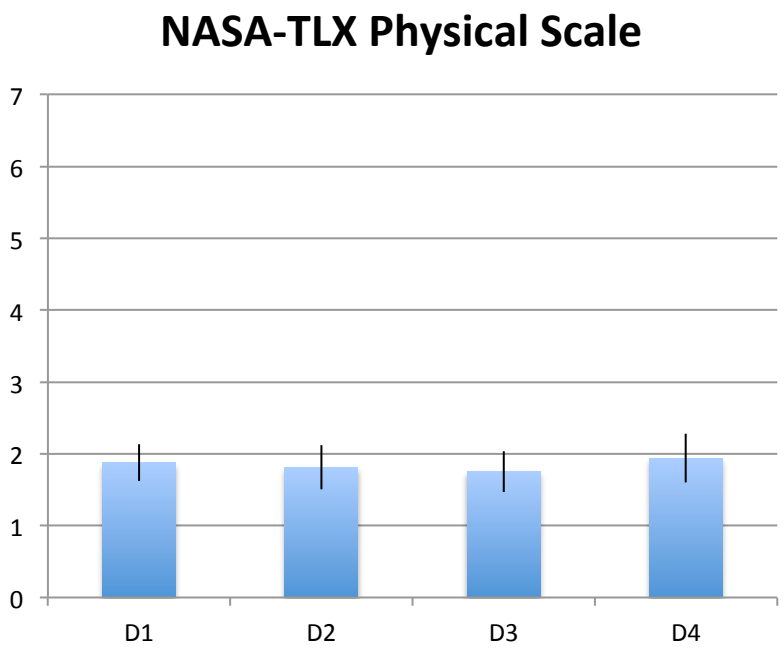
NASA-TLX

- Mental (p = .001)
- Difference between D3 and D4 (p < .001)



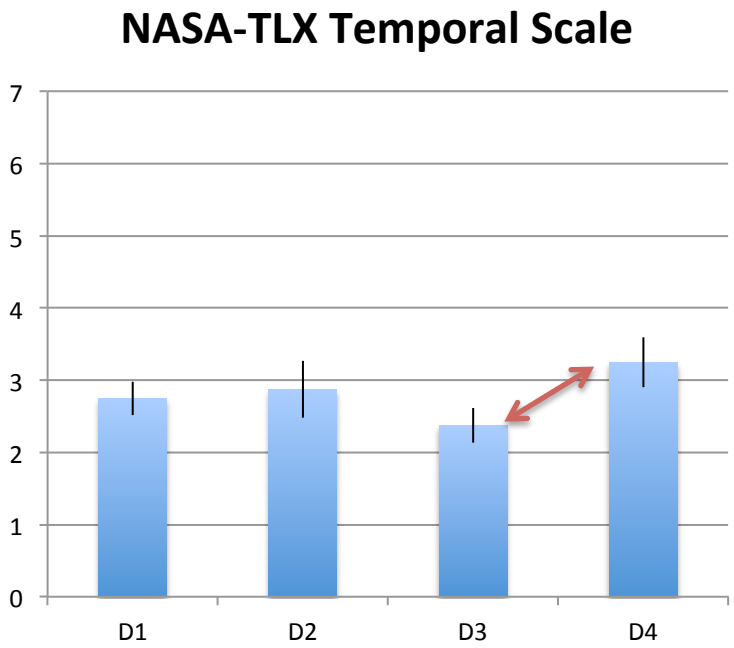
NASA-TLX

- Physical (*NS*)



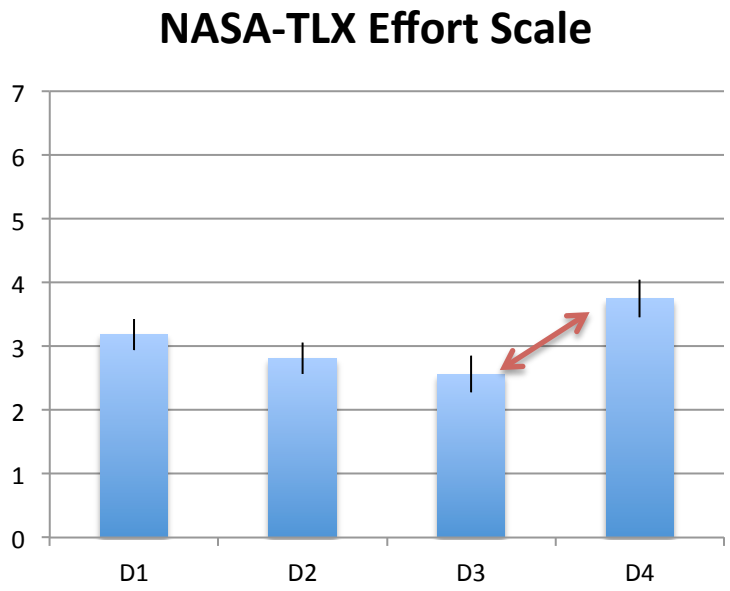
NASA-TLX

- Temporal (marginal, $p = 0.065$)
- Difference between D3 and D4 ($p = 0.023$)



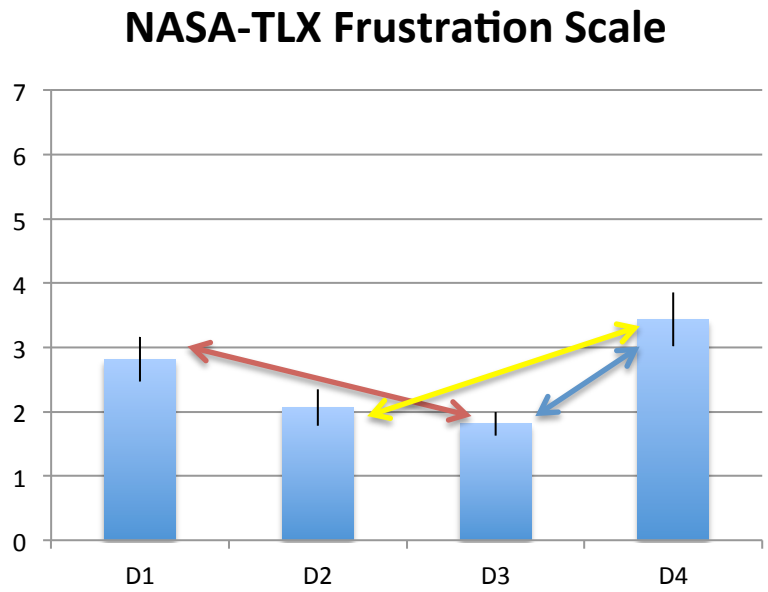
NASA-TLX

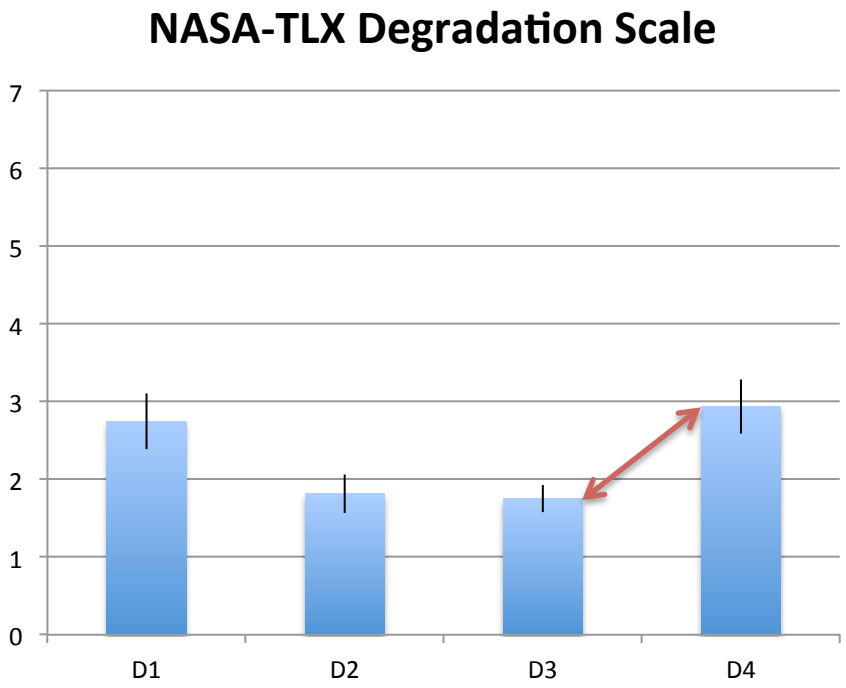
- Effort (p = 0.004)
- Difference between D3 and D4 (p = 0.012)



NASA-TLX

- Frustration ($p < 0.001$)
- Difference between D1 and D3 ($p = 0.021$)
- Difference between D2 and D4 ($p = 0.017$)
- Difference between D3 and D4 ($p = 0.010$)



NASA-TLX

- Degradation (p = 0.001)
- Difference between D3 and D4 (p = 0.034)